

CONDITIONAL TEST METHOD (CTM) 39
MEASUREMENT OF PM_{2.5} AND PM₁₀ EMISSIONS BY DILUTION SAMPLING
(CONSTANT SAMPLING RATE PROCEDURES)

1. SCOPE AND APPLICABILITY

This method describes the procedure that you--the tester--must follow to measure particulate matter emissions equal to or less than a nominal aerodynamic diameter of 2.5 micrometers (μm or microns) (PM_{2.5}) and 10 μm (PM₁₀). You may use this method only with stationary sources.

1.1 Background.

This method expands on the particle sizing capabilities of EPA Method 201A with the addition of a PM_{2.5} sizer (cyclone) behind (or replacing) the PM₁₀ sizer. Furthermore, the capabilities of quantifying and characterizing the condensable particulate matter are improved and expanded with the removal of the in-stack 47-mm, the addition of a system to dilute and cool the sample gas and the addition of a 142-mm filter to collect the filterable PM_{2.5} and the particulate matter condensed through the dilution and cooling of the sample gas. Because the sample gas is cooled and diluted to near ambient conditions, aliquots of the diluted sample gas can be extracted prior to the 142-mm filter for collection and analysis by ambient air methodologies. This method was designed specifically to allow for the collection of particulate matter samples for developing speciation profiles to be used in conjunction with the ambient air speciation sampling network. The calculations and setup are essentially the same as for Method 201A, with additional calculations required for the PM_{2.5} sizer, the dilution system setup and the use of a venturi for monitoring the sampling rate.

Due to the complexity of the calculations, a software program on a computer is used to monitor, calculate, and record all the pertinent data and parameters necessary to operate and use this method. The method hardware and procedures have been modified extensively from the initial version. After several uses at coal-fired boilers, the PVC hardware components were

replaced with 1.5 inch diameter stainless steel components with sanitary flange fittings, including a new mixing chamber.

During the subsequent evaluation field test, the original dilution air and exhaust blowers could not attain the desired dilution ratio and significant deposition in the sample gas-dilution air interface hardware occurred; the difficulty of manually adjusting gate valves to simultaneously and quickly maintain a constant dilution ratio and particle cut size of 2.5 microns was also demonstrated. Consequently, the two hi-vol blowers were replaced with two regenerative blowers and the sample gas-dilution air interface hardware was modified.

Two collaborative field tests (which demonstrated the viability of the new blowers) showed that the problem of the particulate being captured before reaching the 142-mm filter and the speciation 47-mm filters still existed; additionally, the speciation extraction tubing and manifold had as much particulate catch as the sum of the 47-mm filters. Because of these issues, the sample gas and dilution air supply interface was modified by eliminating the static mixing element, modifying an original cone design from SRI, making the mixing chamber 4 inches in diameter and 19 inches long, and adding 3/8 inch ports evenly spaced around the circumference of the 142-mm filter holder inlet (eliminating the need for the speciation extraction tubing and manifold).

1.2 Who should use this method?

This method should be used by those stationary sources quantifying their primary particulate matter emissions. Primary particulate matter emissions include both filterable particulate matter (that material that is solid at stack conditions) and condensable particulate matter (material that is a gas or a vapor at stack condition but becomes solid or liquid at ambient temperature and pressure). This method does not quantify secondary particulate matter which is formed in the atmosphere through chemical reactions between emitted gases or vapors and other substances in the atmosphere. The sources for which this method is most applicable are those with exhaust gas temperatures above approximately 35°C (95°F) and below 425°C (797°F). The

sources of particulate matter emissions that meet this criteria include but are not limited to the following:

- 1.2.1 Fossil-fuel fired steam generators
- 1.2.2 Industrial, Commercial and Institutional boilers
- 1.2.3 Portland cement kilns and clinker coolers
- 1.2.4 Municipal waste combustors
- 1.2.5 Medical waste incinerators
- 1.2.6 Stationary gas turbines
- 1.2.7 Stationary reciprocating internal combustion engines
- 1.2.8 Petroleum refinery catalytic cracking units
- 1.2.9 Fertilizer (Nitrate, Sulfate & Phosphate) production facilities
- 1.2.10 Acid (Nitric, Phosphoric & Sulfuric) production plants
- 1.2.11 Chemical wood pulping plants
- 1.2.12 Reconstituted wood products plants
- 1.2.13 Lime manufacturing plants
- 1.2.14 Wool fiberglass and mineral wool manufacturing plants
- 1.2.15 Glass manufacturing plants
- 1.2.16 Primary and secondary metals smelting and refining facilities
- 1.2.17 Gray iron and steel foundries
- 1.2.18 Carbon black production furnaces

1.3 What can I measure with this method?

You can use this method to measure the coarse and the fine components of total particulate matter emissions. The coarse component includes that particulate matter that has an aerodynamic diameter less than or equal to 10 micrometers (μm) but greater than 2.5 μm . The coarse particulate matter is recovered from the back half of the PM_{10} sizing device (i.e., cyclone I turnaround cup and inner downcomer line), the front half of the $\text{PM}_{2.5}$ sizing device (i.e., cyclone IV cup) and the tubing connecting the two cyclones. The fine component ($\text{PM}_{2.5}$) includes that particulate matter that has an aerodynamic diameter less than or equal to 2.5 μm .

The fine particulate matter is recovered from the exit tube of cyclone IV, the 142 mm Teflon filter and the interior surfaces of all hardware between cyclone IV and the 142 mm Teflon filter (probe, sample venturi, dilution chamber, mixing chamber and front half filter holder). In addition, by summing the coarse and fine components, this method measures PM_{10} .

1.4 Can I use this method to measure condensable emissions?

You can't use this method to measure condensable particulate matter which are captured in the impinger apparatus of Method 202 of Appendix M to CFR part 51. This method measures total primary $PM_{2.5}$ emissions which consists of both condensable particulate matter and $PM_{2.5}$ that is solid at stack conditions. The use of an in-stack filter following cyclone IV is not recommended since this would remove condensation nuclei and may delay the formation of particulate matter from the vapors that exist at stack conditions. Because of the short residence time in the mixing chamber, any delay in the formation of particulate matter will exclude some primary particulate matter that would be formed at the stack exit.

1.5 What am I responsible for?

You are responsible for obtaining the equipment and supplies you will need in this method. You must also develop your own procedures for following this method and any additional procedures to ensure accurate sampling and analytical measurements.

1.6 How can I ensure reliable results?

To obtain reliable results, you must have a thorough knowledge of the test methods that appear in the following list.

- 1.6.1 Method 1 of Appendix A to 40 CFR part 60 - Sample and Velocity Traverses for Stationary Sources.
- 1.6.2 Method 2 of Appendix A to 40 CFR part 60 - Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube).
- 1.6.3 Method 3 of Appendix A to 40 CFR part 60 - Gas Analysis for Carbon Dioxide, Oxygen, Excess Air, and Dry Molecular Weight.

- 1.6.4 Method 4 of Appendix A to 40 CFR part 60 - Determination of Moisture Content in Stack Gases.
- 1.6.5 Method 5 of Appendix A to 40 CFR part 60 - Determination of Particulate Emissions from Stationary Sources.
- 1.6.6 Method 201A of Appendix M to 40 CFR part 51 - Determination of PM_{10} Emissions (Constant Sampling Rate Procedures).

1.7 Do I need to incorporate additional test methods to measure ambient source contribution for particulate matter?

We don't anticipate that you will need additional test methods to measure ambient source contributions because these contributions are insignificant for most sources using this test method. However, when an adjustment for the ambient air particulate matter is needed, a sampler designated as an ambient air monitoring reference or equivalent method in 40 CFR Part 50 Appendix L should be used to quantify the ambient air contribution.

1.8 Can I use this method to measure emissions following a wet scrubber?

You can't use this method to measure emissions following a wet scrubber because this method is not applicable for stack gases containing water droplets. Stacks with entrained moisture droplets may have water droplets larger than the cut sizes for the cyclones and these water droplets contain solids, liquids and dissolved vapors that would become PM_{10} and $PM_{2.5}$ particulate matter when released to the ambient air and the water evaporates. To measure PM_{10} and $PM_{2.5}$ in emissions where water droplets are known to exist, we recommend that you remove the cyclones and use a Method 5 of Appendix A to CFR Part 60 probe heated to $250 \pm 25^\circ$ F and consider the particulate matter catch to be PM_{10} and $PM_{2.5}$ emissions.

1.9 Under what conditions can I use this method as an alternative to EPA Method 17 or EPA Method 5?

This method is not an alternative to EPA Method 17 or EPA Method 5 because it includes the particulate that might be considered condensable.

2. SUMMARY OF METHOD

This method combines Method 201A of Appendix M to 40 CFR part 51 with the PM_{2.5} cyclone from a conventional five-stage cascade cyclone train that includes five cyclones of differing diameters in series and dilutes and cools the sample gas with clean air. The PM_{2.5} cyclone is located after the PM₁₀ cyclone. Stack gas is extracted at a predetermined constant sampling rate to achieve near 100% isokinetics through the in-stack PM₁₀ and PM_{2.5} cyclones. The cyclones separate particles with nominal aerodynamic diameters of greater than 10 microns, less than 10 and greater than 2.5 microns, and allows particles less than or equal 2.5 microns to continue through the sampling train.

Filtered clean dilution air at near-ambient temperature is added to the sample gas (now containing only the particles of less than 2.5 microns in diameter) in a mixing chamber. After sufficient mixing of the dilution air and sample gas, PM_{2.5} is captured on a glass fiber filter bonded with PFTE which is desiccated and weighed gravimetrically to determine the particulate mass (PM_{2.5}) collected on the filter.

Any exposed surfaces of the sample train (e.g., cyclones, sample venturi, mixing chamber, etc.) are rinsed with acetone into clean sample containers. The acetone rinses are evaporated to dryness, desiccated and weighed to determine the particulate mass (PM_{2.5}) for each sample fraction. To minimize variations in the isokinetic sampling conditions, you must establish well-defined limits. Figure 1 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method presents the schematic of this sampling train.

3. DEFINITIONS

[Reserved]

4. INTERFERENCES/LIMITATIONS

[Reserved]

5. SAFETY

Disclaimer. You will have to use hazardous materials (e.g. acetone) and operate test equipment while performing this method. We do not provide information on appropriate safety and health practices. You are responsible for determining the applicability of regulatory limitations and establishing appropriate safety and health practices. Handle materials and equipment properly.

6. EQUIPMENT AND SUPPLIES

6.1 What equipment do I need for the sampling train?

Figures 1 and 2 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method presents a sampling train schematic for use in this test method. The sampling train consists of sample extraction and collection equipment as well as dilution supply air equipment for supplying clean, dry mixing air. The following paragraphs describe the sampling train's primary design features in detail.

6.1.1 Sample Extraction and Collection Equipment.

6.1.1.1 *PM_{2.5} and PM₁₀ sizers.* Choose a stainless steel (316 or equivalent) PM₁₀ and PM_{2.5} sizer that is either electropolished or Teflon[®]-coated. Use a caliper to verify the dimensions of the sizers to within ± 0.02 cm (± 0.01 inch) of the design specifications in Figures 3 and 4 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. It is recommended that the sizers be limited for use at sources with exhaust gas temperatures below 425°C (797°F).

NOTE: Example suppliers of PM₁₀ and PM_{2.5} sizers are:

- Environmental Supply Company, Inc.
2142 Geer Street
Durham, North Carolina 27704
(919) 956-9688

- Apex Instruments, Inc.
P.O. Box 727
125 Quantum Street
Holly Springs, North Carolina 27540
(919) 557-7300
- Andersen Instruments, Inc.
500 Technology Court
Smyrna, Georgia 30082
(770) 319-9999

- 6.1.1.2 *Nozzle.* You must use a nozzle with a sharp tapered leading edge that is stainless steel (316 or equivalent) and is coated with an inert non-reactive material or Teflon[®]. We also recommend that you have a large number of nozzles in small diameter increments available for the sizer being used to ensure that you can select the appropriate nozzle for your field test conditions. Note that when only the PM_{2.5} sizer is used, you must use a nozzle made for the PM_{2.5} sizer. We recommend that you choose one of the nozzles listed in Figures 5 or 6 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method because they meet design specifications. However, if you don't choose a nozzle from this list, then you must choose a nozzle that meets the criteria in paragraph 5.2 of EPA Method 201A of Appendix M to 40 CFR part 51.
- 6.1.1.3 *Pitot tube.* You must use a pitot tube made of heat resistant tubing. The pitot tube can be welded to the probe sheath or attached using appropriate fittings. Follow the specifications for the pitot tube and its orientation to the inlet nozzle given in paragraph 6.1.1.3 of Method 5 of Appendix A to 40 CFR part 60.
- 6.1.1.4 *Probe liner.* You will need a probe liner made of either borosilicate or quartz glass with a heating system capable of maintaining a probe exit gas temperature during sampling within $\pm 3^{\circ}\text{C}$ ($\pm 5.4^{\circ}\text{F}$) of the desired temperature setting of at least 6°C (10°F) above the stack gas temperature or some other temperature as specified by an applicable subpart of the

standards or as approved by the Administrator for a particular application. Since the actual temperature at the outlet of the probe is not usually monitored during sampling, probes constructed according to APTD-0581 and utilizing the calibration curves of APTD-0576 (or calibrated according to the APTD-0576 procedures) will be considered acceptable. Either borosilicate or quartz glass probe liners may be used for stack temperatures up to about 480°C (900°F). Whenever practical, every effort should be made to use borosilicate or quartz glass probe liners. Alternatively, metal liners (e.g., 316 stainless steel, Incolloy 825 or other corrosion resistant metals) made of seamless tubing may be used, subject to the approval of the Administrator.

- 6.1.1.5 *Differential Pressure Transducers.* You will need pressure transducers or equivalent devices. Transducers shall be used for measuring the pitot velocity head (Δp) pressure, the sample venturi and dilution venturi differential pressure, the stack gas static pressure, the static pressure at the mixed/exhaust air relative humidity sensor (blower/pump inlet), and the differential pressure between the dilution air and mixed air relative humidity sensor locations.
- 6.1.1.6 *Heating System/Compartment.* Any heating system capable of maintaining a temperature around the sample venturi within $\pm 3^{\circ}\text{C}$ ($\pm 5.4^{\circ}\text{F}$) of the desired temperature setting of 6°C (10°F) above the stack gas temperature or some other temperature as specified by an applicable subpart of the standards or as approved by the Administrator for a particular application.
- 6.1.1.7 *Temperature Sensors.* You will need to monitor temperatures at the locations listed in Table 3 in Section 17. You will need a temperature sensor capable of measuring temperature to within $\pm 3^{\circ}\text{C}$ ($\pm 5.4^{\circ}\text{F}$) for the probe and heating compartment temperature monitoring and $\pm 1^{\circ}\text{C}$ ($\pm 1.8^{\circ}\text{F}$) when monitoring stack gas, sample gas, and dilution air

temperature. The temperature sensor should be installed so that the sensing tip of the temperature sensor is in direct contact with the sample gas.

- 6.1.1.8 *Sample Venturi.* You will need a Herschel-type sample venturi consisting of a converging cone, venturi throat, and diffuser. The venturi tube shall be constructed of stainless steel and coated with an inert non-reactive material or Teflon[®]. The inlet section to the sample venturi should consist of a converging cone that has an included angle of 21°. The outlet section of the venturi tube shall consist of a diverging cone that has an included angle of 7° to 8°.
- 6.1.1.9 *Couplers, Fittings, Reducers, and Unions.* You will need connectors or couplers coated with Teflon[®] or an inert non-reactive material ranging in diameters from 0.5 to 2.5 inches to assemble the portions of the sampling train (e.g., to connect the PM_{2.5} cyclone to the probe, to connect the probe to the sample venturi, and to connect the sample venturi to the mixing chamber, etc.) You will need stainless steel sanitary flange fittings with seal rings to connect the dilution hose to the inlet of the mixing cone holder and to connect the mixing chamber between the cone holder exit and the 142-mm filter holder inlet. You will need couplers, reducers, and unions to connect the 2.5-inch diameter flexible polyvinyl hoses to the dilution venturi, HEPA filter, dehumidifier, air blowers, and any other component to be connected. Where possible, the assembly should use sanitary flange fittings for a leak-free seal. (**NOTE:** This section does not attempt to address every coupler, fitting, reducer, and/or union necessary to assemble the sampling train. You will need an assortment of such hardware in the field. We recommend that you assemble and leak check the sampling train in the laboratory prior to testing.)
- 6.1.1.10 *Mixing Assembly.* You will need a mixing assembly to mix the clean dry dilution air with the stack sample gas in order to achieve both temperature

and moisture similar to that of ambient air. The mixing assembly consists of two sections, a mixing cone assembly where the dilution air makes initial contact with the stack sample gas and a residence chamber where further mixing of the stack gas and dilution air takes place.

6.1.1.10.1 Mixing Cone and Holder. The initial section of the mixing assembly is the mixing cone and the cone holder. The assembly consists of a mixing cone and a cone holder in which the mixing cone is placed. The cone holder should be constructed of stainless steel; the cone should be made of stainless steel or aluminum and be coated with an inert non-reactive material or Teflon[®]. The mixing cone holder should have a 4-inch (nominal) round inside diameter and a length of approximately 5 inches. The base (or inlet end) of the cone holder should have a circular opening to allow the connection of the sample venturi-cone connector and the inlet of the mixing cone. Near its base, the cone holder should have a 1½ inch diameter sanitary flange connection for the dilution air supply line. A 3/8 inch diameter slipstream of the dilution supply air is diverted through the sample venturi heated compartment, allowing the slipstream of dilution air to be preheated and provide an annulus of heated air to surround the exit of the sample line in the mixing cone. The open face (or exit end) of the cone holder should be flanged to allow for a connection to the mixing tunnel. The mixing cone should be constructed so that it fits firmly inside the cone holder. The cone sides should be perforated so that the dilution supply air can enter the cone and begin mixing with the sample gas stream. (**NOTE:** The sum of the cross-sectional area of the perforations should be less than the cross-sectional area of the dilution supply line connection opening in order to maintain a positive pressure inside the cone holder and thus forcing an equal

distribution of the dilution air through all of the cone's perforation holes.)

- 6.1.1.10.2 *Residence Chamber*. The residence chamber is used to allow the completion of the mixing of the dilution air and stack gas and for any particulate condensation or formation to occur. The residence chamber should be constructed of stainless steel and have sanitary flange-type fittings at both ends to allow for connections to the mixing cone holder and the 142-mm filter inlet. It should have a nominal diameter of 4 inches and a length of approximately 17 inches. The chamber should be coated with an inert non-reactive material or Teflon[®].
- 6.1.1.11 *Filter Holder Assembly*. You should use a filter holder made of aluminum or stainless steel. The inlet or front half of the filter holder should be constructed so that it has a sanitary flange for connecting to the residence chamber and should be coated with an inert non-reactive material or Teflon[®]. (**NOTE:** A modified filter inlet should be used for speciation sampling). The filter support should include a stainless steel screen frit support, a fine mesh frit, a silicone rubber gasket, and a sanitary flange clamp. The filter holder exit should be of a diameter to allow connecting to a 2.5 inch diameter flexible hose coupler. You may use other materials of construction such as stainless steel (316 or equivalent) subject to the approval of the Administrator. The holder design should provide a positive seal against leakage from the outside or around the filter. You should be able to find a commercial filter holder to support 142-mm diameter filters. Commercial size filter holders contain a Teflon[®] O-ring, stainless steel screen which supports the filter, and a final Teflon[®] O-ring.
- 6.1.1.12 *Mixed/Exhaust Air Blower with DC Motor Control*. You will need a regenerative air blower for creating the main air flow through the sampling train. The blower should be at least 1 Hp and be able to provide

30 cubic feet per minute (cfm) at 30 inches of water pressure. The blower should also be equipped with direct current (DC) motor control so that the blower motor hertz setting can be automatically adjusted by a computer program to maintain target dilution ratios and particle cut sizes in the sizers.

- 6.1.1.13 *Relative Humidity (RH) Sensor.* You will need an RH sensor for real-time monitoring of the amount of water vapor (i.e., moisture) in the mixed gas (i.e., stack sample gas and dilution supply air mixture). The RH sensor should have an accuracy of $\pm 2\%$ between 0-90% RH. The operating temperature range of the RH sensor should be from -10 to 50°C.
- 6.1.1.14 *Flexible Hoses.* You will need one or two six foot section of 2.5 inch diameter flexible polyvinyl hoses (e.g., Shop-Vac) to connect the 142-mm filter exit to the mixed/exhaust air blower inlet.

6.1.2 Dilution Supply Air Equipment.

- 6.1.2.1 *Dehumidifier/Cooler.* You will need a dehumidifier for the dilution supply air. The dilution air is necessary to cool the stack gas to near ambient conditions. The dehumidifier should be capable of providing air with a relative humidity of less than 50% at a temperature of less than 95°F.
- 6.1.2.2 *Dilution Air Blower with DC Motor Control.* You will need a regenerative air blower to supply dilution air to the mixing chamber. The blower should be at least 1 Hp and be able to provide 30 cfm at 30 inches of water. The blower should also be equipped with direct current (DC) motor control so that flow can be adjusted during the test to maintain the necessary particulate cut sizes.
- 6.1.2.3 *RH Sensor.* You will need an RH sensor for real-time monitoring of the dilution air moisture. The RH sensor should have an accuracy of $\pm 2\%$ between 0-90% RH. The operating temperature range of the RH sensor should be from -10 to 50°C.

- 6.1.2.4 *HEPA Filter.* You will need a HEPA filter for the dilution air. The HEPA filter should be rated for a minimum of 40 cfm and should provide a minimum of 99.97 Dioctyl-phthalate aerosol particles (DOP) efficiency for 0.30 μm size particles.
- 6.1.2.5 *Dilution Venturi.* You will need a calibrated 2-inch Herschel-type venturi consisting of a converging cone, venturi throat, and diffuser. Since only dry clean air will be contacting the venturi surfaces, the dilution venturi tube may be constructed of any non-reactive material (PVC, stainless steel, aluminum, etc.). The inlet section to the venturi tube shall consist of a converging cone that has an included angle of 21°. The outlet section of the venturi tube shall consist of a diverging cone that has an included angle of 7° to 8°.
- 6.1.2.6 *Temperature Sensors.* You will need to monitor temperature near the relative humidity sensor (see Table 3 in section 17). You will need a temperature sensor similar to those in section 6.1.1.6.
- 6.1.2.7 *2.5-to-1.5 inch Reducer.* You will need a reducer made of an inert non-reactive material (aluminum, stainless steel, etc.). One end is 2.5 inch diameter for connecting to the flexible hose from the HEPA filter exit. The other end is a 1.5 inch sanitary flange type fitting that connects to the 1.5 inch dilution air supply port in the mixing cone holder.
- 6.1.2.8 *Flexible Hoses.* You will need three or four six foot sections of 2.5 inch diameter flexible polyvinyl hoses (e.g., Shop-Vac) to connect the dehumidifier, dilution air blower, dilution venturi, HEPA filter, and mixing chamber.
- 6.1.2.9 *Hose Couplers.* You will need multiple hose couplers that are 2.5 inches in diameter. These are used for connecting the flexible hoses to the various train components. In addition, you will need several couplers that have been modified by plugging the interior. These are used for sealing or capping off various parts of the train during setup, leak checking,

transporting of recovered samples, etc. It is recommended that these plugged couplers be CLEARLY differentiated from the normal hose coupler to avoid using a plugged coupler in place of a normal coupler.

6.2 What equipment do I need for leak checking the equipment before and after performing a test.?

You will need the following equipment to leak check the hardware.

- 6.2.1 Pump. You may use a vacuum gauge, leak-free pump, and a dry gas meter (DGM) capable of measuring volume to within 2 percent, and related equipment, (See Figure 5-1 of Method 5).
- 6.2.2 Leak Check Assembly. You will need a leak check assembly to attach to the exit of the 142-mm filter holder to allow performing leak checks. The assembly consists of a 2.5 inch PVC tube section with a port connection with a female quick-connect fitting, a normal hose coupler, and a plugged coupler.
- 6.2.3 Umbilical Line. You will need an umbilical line to connect to the leak check assembly quick-connect and the pump.

6.3 What equipment do I need for sample recovery?

You will need the following equipment to quantitatively determine the amount of particulate matter recovered from the sampling train.

- 6.3.1 Probe Nozzle, PM_{2.5} and PM₁₀ sizers, Probe Liner, Sample Venturi, Mixing Cone, Residence Chamber, and Filter Holder brushes. You will need nylon or Teflon[®] bristle brushes with stainless steel wire or Teflon[®] handles. The probe brush should have extensions (at least as long as the probe) constructed of stainless steel, Teflon[®], or similarly inert material. The brushes shall be properly sized and shaped to brush out the nozzles, PM_{2.5} and PM₁₀ sizers, probe liner, sample venturi tube, sample venturi-cone connector, mixing cone, residence chamber, and 142-mm filter holder inlet.

- 6.3.2 Wash Bottles. We recommend that you have two glass or Teflon[®] wash bottles. Alternatively, polyethylene wash bottles may be used. We recommend that acetone not be stored in polyethylene bottles for longer than a month.
- 6.3.3 Glass Sample Storage Containers. You should use chemically resistant, borosilicate glass bottles with screw-on caps, to collect the acetone rinses of the sampling train. You will need 125 ml and 250 ml bottles. The screw cap liners should be constructed of either rubber-backed Teflon[®] or constructed to be leak-free and resistant to chemical attack by acetone. (Narrow mouth glass bottles are less prone to leakage.) Alternatively, polyethylene bottles may be used.
- 6.3.4 Petri dishes. We recommend that you use glass or polyethylene petri dishes for storing the 142-mm Teflon[®] filter samples. We may approve other storage containers such as wax sleeves.
- 6.3.5 Funnel. You should use a glass or polyethylene funnel to aid in collecting acetone rinses into the sample bottles.

6.4 What equipment will I need for sample analysis?

You will need an analytical balance capable of measuring particulate mass to within 0.01 milligram (mg). The balance should be in a controlled environment capable of maintaining a relative humidity of less than 50% and a temperature of 68°F ± 10°F.

6.5 Can I use additional equipment in the sample train?

- 6.5.1 Data Acquisition (DAQ) Module (Optional). You may want to use a DAQ module capable of monitoring and recording flow velocities, absolute and differential pressures, and temperatures at various locations in your sampling train. The DAQ can also be programmed to perform real-time calculations in order to ensure that you are achieving your PM₁₀ and PM_{2.5} cut sizes during sampling. The DAQ module could be programmed to provide real-time calculations for stack gas moisture and velocity, sampling rate % isokinetics,

flow rate through the cyclones, sample flow rate, dilution ratio, dilution air flow rate, and cyclones cut sizes.

7. REAGENTS AND STANDARDS

7.1 What reagents do I need for sample collection?

You must use a 142-mm filter made of borosilicate microfibers reinforced with woven glass cloth and bonded with PTFE. The filter must also have an efficiency of at least 99.95% (<0.05% penetration) on 0.3 micron dioctyl phthalate smoke particles. Conduct the filter efficiency test in accordance with ASTM Method D 2986-71, 78, 95a (incorporated by reference). Alternatively, you may use test data from the supplier's quality control program. Depending on your application and project data quality objectives (DQOs), filters are commercially available in a variety of sizes. The filter setup in this method specifies a 142-mm filter. Other filter sizes may be used depending upon your hardware and testing program.

7.2 What reagents do I need for sample recovery?

You must use acetone, reagent grade, less than or equal to (\leq) 0.001% (1 ppm) residue that is stored in glass bottles. You must run acetone blanks and may subtract the acetone blank contribution from the acetone rinse sample catch weights. Do not subtract a blank value greater than 0.001 weight percent of acetone used from the sample weight.

7.3 What reagents do I need for sample analysis?

You will not need any reagents for sample analysis. You will simply weigh the samples using the analytical balance described in Section 6.3.

8. SAMPLE COLLECTION, PRESERVATION, STORAGE, AND TRANSPORT

8.1 What qualifications do I need to perform this test method?

This is a complex test method. To obtain reliable results, you must be trained and experienced in the use of in-stack filtration systems (such as, cyclones, impactors, and thimbles) and their operations, isokinetic sampling procedures in general, EPA Method 201A, and the procedures of this test method.

8.2 What preparations must I do prior to the test?

8.2.1 Pretest Preparation.

8.2.1.1 *Filter Check.* Check filters visually against light for irregularities, flaws, or pinhole leaks. Label the shipping containers (glass or polyethylene petri dishes, wax sleeves, etc.), and keep each filter in its identified container at all times except during sampling and weighing.

8.2.1.2 *Filter Weighing.* Desiccate the filters at $20 \pm 5.6^{\circ}\text{C}$ ($68 \pm 10^{\circ}\text{F}$) and ambient pressure for at least 24 hours. Weigh each filter (or filter and shipping container) at intervals of at least 6 hours to a constant weight (i.e., ≤ 0.05 mg change from previous weighing). Record results to the nearest 0.01 mg. During each weighing, the period for which the filter is exposed to the laboratory atmosphere shall be less than 2 minutes.

8.2.1.3 *Sampling Train Cleaning.* Rinse all portions of the train from which PM_{10} and $\text{PM}_{2.5}$ will be recovered (e.g., nozzle, PM_{10} and $\text{PM}_{2.5}$ sizers, probe, sample venturi, connectors, mixing cone, residence chamber, and filter holder inlet) with hot tap water and then wash in hot soapy water. Next, rinse three times with tap water, follow by three additional rinses with deionized, distilled water and allow to air dry. Cover all openings where contamination can occur until the sampling train is assembled for sampling.

8.3 What must I do to properly set up the test?

You must perform the following steps to properly set up for this test:

- Determine the sampling site location and traverse points.
- Calculate probe/cyclone blockage.
- Verify the absence of cyclonic flow.
- Complete a preliminary velocity and temperature profile and select a nozzle(s).
- Conduct preliminary moisture measurements

8.3.1 Sampling Site Location and Traverse Point Determination. Follow the standard procedures in Method 1 of Appendix A to 40 CFR part 60 to select the appropriate sampling site. Then do all of the following:

8.3.1.1 *Sampling site.* Choose a location that maximizes the distance from upstream and downstream flow disturbances.

8.3.1.2 *Traverse points.* Select the same number of traverse points described in paragraph 4.1.2 of Method 201A of Appendix M to 40 CFR part 51 and shown in Figure 7 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. The required maximum number of traverse points at any location is 12. Prevent the disturbance and capture of any solids accumulated on the inner wall surfaces by maintaining a 1 inch distance from the stack wall ($\frac{1}{2}$ inch for sampling locations less than 24 inches in diameter).

8.3.1.2.1 Round or rectangular duct or stack. If a duct or stack is round with two ports located 90° apart, use six sampling points on each diameter. Use a 3x4 sampling point layout for rectangular ducts or stacks. Consult with the Administrator to receive approval for other layouts before you use them.

8.3.1.2.2 Sampling ports. When you are using only the PM_{2.5} sizer (cyclone), you may use the existing ports in most of the sampling port locations installed for sampling by Method 5 or Method 17 of Appendix A to 40 CFR part 60 for total filterable particulate sampling. When you

use the combination of the PM_{10} and $PM_{2.5}$ sizers at the same locations, you will probably need new sampling ports. When you must use nozzles smaller than 0.16 inches in diameter, the sampling port diameter must be at least 6 inches. Do not use the conventional 4-inch diameter port because it will not support the length of the nozzle extending from the PM_{10} cyclone. [NOTE: If the port nipple is short, you may be able to “hook” the sampling head through a smaller port into the duct or stack.]

8.3.2 Probe/Cyclone Blockage Calculations. Follow the procedures in the next two paragraphs, as appropriate.

8.3.2.1 *Ducts with diameters greater than 24 inches.* Minimize the blockage effects of the combination of the in-stack nozzle/cyclones and filter assembly for ducts with diameters greater than 24 inches by keeping the cross-sectional area of the assembly at 3% or less of the cross-sectional area of the duct.

8.3.2.2 *Ducts with diameters from 18 to 24 inches.* Ducts with diameters from 18 inches to 24 inches have blockage effects ranging from 3% to 6%, as illustrated in Figure 8 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. Therefore, when you conduct tests on these small ducts, you must adjust the observed velocity pressures for the estimated blockage factor whenever the combined sampling apparatus blocks more than 3% of the stack or duct (see Section 8.8.2 regarding the probe blockage factor and the final adjusted velocity pressure).

8.3.2.2 *Ducts with diameters less than 18 inches.* Follow the procedures in EPA Method 1A.

8.3.3 Cyclonic flow. Do not use the combined cyclone sampling head at sampling locations subject to cyclonic flow. Also, you must follow Method 1 procedures to determine the presence or absence of cyclonic flow. Then perform the

following calculations. [NOTE: You can minimize cyclonic flow conditions by placing gas flow straighteners upstream of the sampling location.]

- 8.3.3.1 *Find the angle that has a null velocity pressure.* Insert the S-type pitot tube at each of the traverse points and rotate until you locate the angle that has a null velocity pressure.
- 8.3.3.2 *Determining a sampling location.* Average the absolute values of the angles that have a null velocity pressure. Do not use the sampling location if the average absolute value exceeds 20°.
- 8.3.4 Preliminary velocity profile. Conduct a preliminary Method 2 of Appendix A to 40 CFR part 60 velocity traverse, as well as the measurements below. The purpose of the velocity profile is to determine all of the following:
- The gas sampling rate for the combined probe/cyclone sampling head.
 - The appropriate nozzle(s) to maintain the required velocity pressure range and isokinetic range.
 - The necessary sampling duration to obtain sufficient particulate catch weights.
- 8.3.4.1 *Preliminary traverse.* You must use an S-type pitot tube with a conventional thermocouple to conduct the preliminary traverse. Conduct the preliminary traverse as close as possible to the anticipated testing time on sources that are subject to hour-by-hour gas flow rate variations of approximately $\pm 20\%$ and/or gas temperature variations of approximately $\pm 50^\circ\text{F}$. [NOTE: You should be aware that these variations can cause errors in the cyclone cut diameters and the isokinetic sampling rates.]
- 8.3.4.2 *Velocity pressure range.* Insert the S-type pitot tube at each traverse point and record the range of velocity pressures measured on the Method 2 of Appendix A to 40 CFR part 60 data form. You will use this later to select the appropriate nozzle(s).
- 8.3.4.3 *Initial gas stream viscosity and molecular weight.* Determine the average gas temperature; estimate the stack gas oxygen, carbon dioxide, and

moisture content. You will use this information to calculate the initial gas stream viscosity (Equation 3) and molecular weight (Equations 1 and 2).

[**NOTE:** For these initial calculations, you must either assume a moisture content (based on prior knowledge of the process); estimate moisture following the procedures outlined in EPA Method 4 in 40 CFR 60, Appendix A; use a wet bulb-dry bulb measurement device; or use a hand-held hygrometer measurement device for stack gas temperatures less than 160°F.]

8.3.4.4 *Particulate matter concentration in the gas stream.* Determine the particulate matter concentration in the gas stream through qualitative measurements or estimates. Having an idea of what the particulate concentration is in the gas stream will help you determine the appropriate sampling time to acquire sufficient mass of particulate matter for better accuracy at the source emission level. The collectable particulate matter weight requirements depend primarily on the types of chemical analyses needed to characterize the emissions. Estimate the collectable particulate matter concentrations in the >10 micrometer, ≤ 10 and >2.5 micrometers, and ≤ 2.5 micrometer size ranges.

8.3.5 Moisture Measurements. Determine the moisture content of the stack gas using Approximation Method 4 or its alternatives (e.g., use historical moisture data) for the purpose of making initial isokinetic sampling rate settings.

8.3.6 Stack Gas Pressure (absolute). Determine the stack pressure using the barometric pressure and measured stack gauge pressure.

8.4 Why must I perform pre-test calculations.

If you are not using a computer program to control the sampling rate, you must perform pre-test calculations to help select the appropriate gas sampling rate through cyclone I (PM₁₀) and cyclone IV (PM_{2.5}). Choosing the appropriate sampling rate will allow you to maintain the

appropriate particle cut diameters based upon preliminary gas stream measurements, as specified in Table 2 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method.

- 8.4.1 Gas sampling rate. The gas sampling rate is defined by the performance curves for both cyclones, as illustrated in Figure 9 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. You must use the calculations in section 8.5 to achieve the appropriate cut size specification for each cyclone. The optimum gas sampling rate is the overlap zone defined as the range below the 2.25 micrometer curve of cyclone IV down to the 11.0 micrometer curve of cyclone I (area between the two dark, solid lines in Figure 9 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method).
- 8.4.2 Choosing the appropriate sampling rate. You must select a gas sampling rate in the middle of the overlap zone (discussed in paragraph 8.4.1 of this section), as illustrated in Figure 9 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method to maximize the acceptable tolerance for slight variations in flow characteristics at the sampling location. The overlap zone is also a weak function of the gas composition. [NOTE: You should be aware that the acceptable range is limited, especially for gas streams with temperatures less than approximately 100°F.]
- 8.4.3 Choosing the appropriate dilution ratio. You should use a dilution ratio of approximately 10:1 to 40:1 to achieve near ambient conditions. The appropriate dilution ratio will allow you to cool the sample gas to near ambient temperature in order to mimic PM_{2.5} formation that occurs downstream of the stack exit. The appropriate dilution ratio will also keep moisture from condensing from the cooled sample gas stream.

8.5 What pre-test calculations must I perform?

If you are not using a computer program to control the operation of the sampling train, you must perform all of the calculations in Table 1 of this paragraph, and the calculations described in paragraphs 8.5.1 through 8.5.5 of this section.

Table 1. Pretest Calculations

If you are using...	To calculate...	Then use...
Preliminary data	dry gas molecular weight, M_d	Equation 1
Dry gas molecular weight (M_d) and preliminary moisture content of the gas stream	wet gas molecular weight, M_w	Equation 2 ^a
Stack gas temperature, oxygen and preliminary moisture content of the gas stream	gas viscosity, μ	Equation 3
Barometric pressure and average static (gauge) stack gas pressure	stack gas pressure (absolute), P_s	Equation 4
Gas viscosity, μ	Cunningham correction factor ^b , C	Equation 5
Assumed Reynolds number ^c (N_{re}) $N_{re} < 3162$	preliminary lower limit cut diameter for cyclone I, D_{50LL}	Equation 6
D_{50LL} from Equation 6	cut diameter for cyclone I for middle of the overlap zone, D_{50t}	Equation 7
D_{50t} from Equation 7	final sampling rate for cyclone I, Q_I (Q_s)	Equation 8
Q_I (Q_s) from Equation 8	(verify) the assumed Reynolds number	Equation 9
Assumed Reynolds number ^c (N_{re}) $N_{re} \geq 3162$	lower limit cut diameter for cyclone I, D_{50LL}	Equation 10
Q_s from Equation 8	estimated sampling rate through cyclones I and IV (at standard conditions, wet basis), $Q_{sw(std)}$	Equation 11
$Q_{sw(std)}$ from Equation 11	estimated dilution air flow rate (at standard conditions, wet basis), $Q_{dw(std)}$	Equation 12
Sampling rate through cyclones I and IV (Q_s); stack pressure and temperature; and estimated molecular weight, temperature and pressure at the sample venturi	target sample venturi pressure differential setting, ΔH_1	Equation 13
Dilution air flow rate ($Q_{dw(std)}$) and estimated molecular weight, temperature and pressure at the dilution venturi	target dilution venturi pressure differential setting, ΔH_2	Equation 14

Table 1. Pretest Calculations

If you are using...	To calculate...	Then use...
Use preliminary data to calculate initial stack gas velocity (v_s)	velocity of stack gas (v_s)	Equation 15
Use Equations 16, 17, and 18 to recalculate v_s for C_p and probe blockage (b_f) prior to calculating the nozzle diameter for the acceptable sampling rate	adjusted velocity of stack gas (v_s)	Equation 15 (Adjusted)
Sampling rate through cyclones (Q_s) and adjusted stack gas velocity (v_s)	nozzle diameter for acceptable sampling rate (D_n)	Equation 19
Nozzle diameter (D_n)	nozzle area (A_n)	Equation 20
Sampling rate through cyclones (Q_s) and nozzle diameter (D_n)	sample gas velocity in nozzle (v_n)	Equation 21
Gas viscosity (μ), sampling rate through cyclones (Q_s), and adjusted stack gas velocity (v_s)	minimum (R_{min}) and maximum (R_{max}) nozzle/stack velocity ratio parameter to maintain isokinetic range of 80 to 120%.	Equations 22 and 23
Nozzle velocity calculated in Equation 21	minimum stack gas velocity (v_{min}) if R_{min} (Equation 22) is an imaginary number (value under the square root function is negative) or less than 0.5	Equation 24
	or	
	minimum stack gas velocity (v_{min}) if R_{min} (Equation 22) is greater than 0.5	Equation 25
Nozzle velocity calculated in Equation 21	maximum stack gas velocity (v_{max}) if R_{max} is equal to or less than 1.5	Equation 26
	or	
	maximum stack gas velocity (v_{max}) if R_{max} is greater than 1.5	Equation 27
Preliminary data (i.e., P_s , T_s , and M_w), C_p , and v_{min}	minimum stack gas velocity pressure (Δp_{min}) which will maintain an isokinetic range of 80% to 120%	Equation 28

Table 1. Pretest Calculations

If you are using...	To calculate...	Then use...
Preliminary data (i.e., P_s , T_s , and M_w), C_p , and v_{\max}	maximum stack gas velocity pressure (Δp_{\max}) which will maintain an isokinetic range of 80% to 120%	Equation 29
Preliminary traverse data (Δp_1), number of traverse points (N), and total run time (t_r)	sampling time at point 1 (t_1) rounded to the nearest 1/4 minutes.	Equation 30
^a Use Method 4 of Appendix A to 40 CFR part 60 to determine the moisture content of the stack gas. Use a wet bulb-dry bulb measurement device or hand-held hygrometer to estimate moisture content of sources with gas temperature less than 160°F.		
^b For the lower cut diameter of cyclone IV, 2.25 micrometer.		
^c Verify the assumed Reynolds number using the procedure in paragraph 8.5.1, below, before proceeding to Equation 13.		

8.5.1 The assumed Reynolds number. Verify the assumed Reynolds number (N_{re}) by substituting the sampling rate (Q_s) calculated in Equation 8 into Equation 9. Then use Table 2 of this paragraph to determine if the N_{re} used in Equation 6 was correct.

Table 2. Verification of the Assumed Reynolds Number

If the N_{re} is ...	Then ...	And ...
< 3162	Calculate ΔH_1 for the sample venturi	
≥ 3162	Recalculate D_{50LL} using Equation 10	Substitute the “new” D_{50LL} into Equation 7 to recalculate D_{50t}

8.5.2 Final sampling rate. You must recalculate the final sampling rate (Q_s) if the assumed Reynold’s number used in your initial calculation is not correct. Use Equation 8 to recalculate the optimum sampling rate (Q_s).

- 8.5.3 Sample venturi pressure settings. Use Equation 13 to calculate the sample venturi pressure setting (ΔH_1) after you calculate the optimum sampling rate and confirm the Reynolds number. [NOTE: The stack gas temperature may vary during the test which could affect the sampling rate. If this occurs, you must make slight adjustments to the blower controls to achieve the sample venturi ΔH_1 to maintain the correct constant cut diameters. Therefore, use Equation 13 to recalculate the ΔH_1 values for 50°F above and below the stack temperature measured during the preliminary traverse (see section 8.3.4.1) and document this information in the Tables, Diagrams, Flowcharts, and Validation Data section of this method under Table 3.]
- 8.5.4 Dilution air supply rate. You must calculate the rate of dilution air required to achieve the desired dilution ratio to keep condensation of moisture and particulate from occurring in the mixing chamber or residence chamber. [NOTE: If condensation is observed after a test, the dilution ratio may be increased. The dilution air supply rate must be recalculated.]
- 8.5.5 Dilution venturi pressure settings. Use Equation 14 to calculate the dilution venturi ΔH_2 after you calculate the optimum dilution air supply rate based on the desired dilution ratio.
- 8.5.6 Choosing a sampling nozzle. You must select one or more nozzle sizes to provide for near isokinetic sampling rates (that is, 80% to 120%). This will also minimize any isokinetic sampling errors for the 10 micrometer and 2.5 micrometer particles at each point. First calculate the mean stack gas velocity, v_s , using Equation 15. Look at Section 8.8.2 for information on correcting for blockage and use of different pitot tube coefficients. Then use Equation 19 to calculate the diameter of a nozzle that provides for isokinetic sampling at the mean stack gas velocity at flow Q_s . From the available nozzles just smaller and just larger of this diameter, D , select the most promising nozzle(s). Perform the following steps for the selected nozzle(s).

- 8.5.6.1 *Minimum/maximum nozzle/stack velocity ratio.* Use Equation 22 to calculate the minimum nozzle/stack velocity ratio, R_{\min} . Use Equation 23 to calculate the maximum nozzle/stack velocity ratio, R_{\max} .
- 8.5.6.2 *Minimum gas velocity.* Use Equation 24 to calculate the minimum gas velocity (v_{\min}) if R_{\min} is an imaginary number (negative value under the square root function) or if R_{\min} is less than 0.5. Use Equation 25 to calculate v_{\min} if R_{\min} is greater than or equal to 0.5.
- 8.5.6.3 *Maximum stack velocity.* Use Equation 26 to calculate the maximum stack velocity (v_{\max}) if R_{\max} is less than 1.5. Use Equation 27 to calculate the stack velocity if R_{\max} is greater than or equal to 1.5.
- 8.5.6.4 *Conversion of gas velocities to velocity pressure.* Use Equation 28 to convert v_{\min} to minimum velocity pressure, Δp_{\min} . Use Equation 29 to convert v_{\max} to maximum velocity pressure, Δp_{\max} .
- 8.5.6.5 *Comparison of minimum and maximum velocity pressures.* Compare minimum and maximum velocity pressures with the observed velocity pressures at all traverse points during the test (see section 8.3.4.1 of this section).
- 8.5.7 Optimum sampling nozzle. The nozzle you selected is appropriate if all the observed velocity pressures during the preliminary test fall within the range of the Δp_{\min} and Δp_{\max} . Make sure the following requirements are met. Then follow the procedures in section 8.5.7.1 and 8.5.7.2.
- Choose an optimum nozzle that provides for isokinetic sampling conditions as close to 100% as possible. This is prudent because even if there are slight variations in the gas flow rate, gas temperature, or gas composition during the actual test, you have the maximum assurance of satisfying the isokinetic criteria. Generally, one of the two candidate nozzles selected will be closer to optimum (see Section 8.5.6).

- You can only have one point that is outside the minimum-to-maximum range. However, you can select two or more nozzles to achieve the isokinetic specification.

8.5.7.1 *Precheck.* Visually check the selected nozzle for dents before use.

8.5.7.2 *Attach the pre-selected nozzle.* Screw the pre-selected nozzle onto the main body of the cyclone using Teflon[®] tape. If you are using both sizers, connect the cyclone IV inlet to the outlet of cyclone I (see Figure 3 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method).

8.5.8 Nozzle Area. Once you have selected the optimum sampling nozzle, calculate the nozzle opening cross-sectional area using Equation 20.

8.6 How do I assemble the sampling train?

First, you must assemble the train and then leak check the train from the cyclone sampling head(s); if necessary, perform a separate leak check on the diluted section of the train (mixing chamber, residence chamber, filter). Leak check the dilution and sample venturi pressure lines; leak check the pitot tubes following Section 8.1 of EPA Method 2. Use the following procedures to prepare the sampling train. [NOTE: Do not contaminate the sampling train during preparation and assembly. You must keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.]

8.6.1 Activities to perform in a controlled environment. Several of the components of the stack sampling equipment can be assembled prior to setting up the equipment at the stack. This practice will minimize contamination and breakage. Such activities are discussed below.

8.6.1.1 *Sampling head.* Assemble the combined cyclone sizers. The O-rings used in the train have a temperature limit of approximately 400°F. However, Teflon[®] O-rings can withstand 600°F without sealing problems. You must use cyclones with stainless steel sealing rings when stack temperatures exceed 600°F. You must keep the nozzle covered to protect

it from nicks and scratches and keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

8.6.1.2 *Filter (142-mm) and Filter Holder.* Use tweezers or clean disposable surgical gloves to place a labeled (identified) and pre-weighed filter on the filter support screen in the back half of the filter holder. You must center the filter so that the sample gas stream will not circumvent the filter. After placing the O-ring on the holder correctly, join the two filter holder halves by placing the front half (or inlet) filter holder on top of the filter and back half filter holder; tape the joint with Teflon[®] tape. Clamp the two filter holder halves together using the 6-inch sanitary flange clamp. [NOTE: The 142-mm filter should be tared prior to placing in the filter holder].

8.6.1.3 *Residence Chamber and Filter Holder (142-mm).* Place the residence chamber exit flange on the filter holder inlet flange, making sure the gasket seal ring is properly seated between the two flanges. Tape the joint with Teflon[®] tape and place a 4-inch diameter (nominal) stainless steel sanitary clamp over the tape to complete the seal. [NOTE: If speciation sampling is being performed, the filter inlet can be constructed with taps or connectors so that filter holders or deluder systems can be attached directly to the filter holder inlet. The filter holder must be properly aligned with the residence chamber support brackets to allow the vertical placement of any denuder sampling legs being utilized.]

8.6.2 Activities to perform at the stack. The various components of the dilution supply are connected using 6-foot (typical) sections of 2.5-inch diameter flexible polyvinyl hose (Shop-Vac type) and the hose couplers that are made for using these hoses. When references are made to connecting the hoses to equipment, the connections are made with hose couplers.

8.6.2.1 *Probe-Heated Compartment-Mixing Cone Holder.* Insert the sample venturi-cone connector (SVCC) tubing through the tee used to create the

annulus space for the preheated dilution air slipstream. Connect the tubing to the mixing cone holder tubing and to the tee. Connect the sample venturi ball fitting to the SCVV socket fitting with a pinch clamp. Attach the inlet socket of the sample venturi to the probe's exit ball fitting with a pinch clamp and secure the probe with the probe holder bracket.

- 8.6.2.2 *Mixing Cone-Residence Chamber-Filter Holder.* Place the mixing cone inside the cone holder as shown in Figure 2; make sure the SVCC tubing end is centered in the annulus space. Join the cone holder flange to the residence chamber flange, making sure the gasket seal ring is correctly located between the two flanges. Tape the joint with Teflon[®] tape prior to using a 4-inch diameter (nominal) stainless steel sanitary clamp to complete the seal. Attach the sanitary flange end of the reducer to the 1.5-inch flange on the mixing cone holder, again making sure the gasket seal ring is properly placed between the flanges; use a 1.5-inch clamp to complete the seal. Confirm that the filter holder exit and the 2.5-inch end of the reducer are capped by plugged hose couplers (which will be replaced prior to the testing).
- 8.6.2.3 *Mixed/Exhaust Air Blower.* Attach one of the 6-foot flexible hoses to the inlet of the mixed or exhaust air blower. The other end will be connected to the filter holder exit (after removing the plugged coupler) after the probe is inserted into the stack port (after leak checking).
- 8.6.2.4 *Dehumidifier-Dilution Air Blower.* Using one of the flexible hose sections, connect the dilution air blower to the dehumidifier.
- 8.6.2.4 *Dilution Venturi.* Connect the upstream end of the dilution venturi directly to the exit of the dilution air blower using a hose coupler.
- 8.6.2.5 *HEPA Filter Housing.* Insert one end of a section of flexible hose into the inlet of the HEPA filter housing and connect the other end to the exit of the dilution venturi. Insert the end of a cleaned flexible hose section into the exit of the HEPA filter housing and place a plugged hose coupler on

the opposite end to seal the hose until testing begins. This end will be connected after the probe is inserted into the stack to the reducer attached to the mixing cone holder.

8.7 How do I leak check the sampling train?

You must conduct a pre-test leak check of the sampling train. You may leak check the diluted section separately from the non-diluted section or you may choose to leak check both together. Use the procedures outlined below to leak check the entire sampling system.

8.7.1 Pretest Leak Check. Because of the complexity of the equipment set-up for this test, a pretest leak check of the stack gas sample (or non-diluted) section of the sampling train must be performed; for practical purposes, this means from the nozzle to the mixing cone holder exit. Similarly, perform a pretest leak check of the mixed/exhaust (or diluted) section of the sampling train. If a leak check of both sections (from the nozzle to the filter holder exit) is performed, the maximum allowable leak rate is the same as for the non-diluted section only, 0.02 cfm. The maximum allowable for the mixed section is 0.05 cfm. This is loosely based on the criteria from Method 5 (maximum leak rate of 0.02 cfm and an estimated maximum sampling rate of 1.5 cfm yielding a rate percentage of 1.33% ($0.02 / 1.5$) and a minimum flow rate through the mixed section of 4 cfm (dilution ratio of 10); specifically, $0.0133 \times 4 = 0.052$ which is rounded to 0.05 cfm. The importance of minimizing leaks in the mixed section is related to the accuracy of the dilution ratio calculated value and the mixed air moisture calculated value. These parameters are used to correct the sample volume measured through the sample venturi from a wet basis to a dry basis and any error in the moisture value impacts the dry sample volume.

8.7.1.1 *Non-diluted Section Leak Check.* You must plug the sample venturi pressure taps (one way is to connect the two taps with rubber tubing) and the mixing cone holder exit (a 4-inch cap designed for use with sanitary flange fittings works well). Connect the leak check assembly to the

dilution air supply inlet port of the mixing cone holder. Connect the umbilical line from the pump to the leak check assembly. Leak check the train by plugging the nozzle and pulling a 76 mm (3 in.) Hg vacuum.

Leakage rates in excess of 4 percent of the average sampling rate or $0.00057 \text{ m}^3/\text{min}$ (0.02 cfm), whichever is less, are unacceptable. Enter the leak check results on the field test data sheet for the specific test. [NOTE: Do not conduct a leak check during port changes.]

8.7.1.2 *Diluted Section Leak Check.* You must leak check the diluted section either from the nozzle or from the residence chamber inlet through the filter holder exit. If you leak check from the nozzle, the non-diluted section of the train (nozzle to mixing cone holder) must be leak checked first and meet the 0.02 cfm leak rate criteria. Connect the leak check assembly to the filter holder exit. Connect the umbilical line from the pump to the leak check assembly. Leak check the train by plugging either the nozzle or the residence chamber inlet and pulling a 76 mm (3 in.) Hg vacuum. Leakage rates in excess of 0.05 cfm are unacceptable (0.07 cfm if leak checking is from the nozzle). Enter the leak check results on the field test data sheet for the specific test. [NOTE: Do not conduct a leak check during port changes.]

8.7.1.3 *Pitot Tube Assembly.* You must perform a leak check of the pitot tube assembly. Capillary tubing or surge tanks installed between the manometer and pitot tube may be used to dampen Δp fluctuations. Conduct a pretest leak-check as follows: (1) blow through the pitot impact opening until at least 7.6 cm (3.0 in.) H_2O velocity head registers on the manometer; then, close off the impact opening. The pressure shall remain stable for at least 15 seconds; (2) do the same for the static pressure side, except using suction to obtain the minimum of 7.6 cm (3.0 in.) H_2O . Other leak-check procedures, subject to the approval of the Administrator, may be used.

- 8.7.1.4 *Venturi Pressure Lines.* You must perform a leak check of the sample and dilution venturi pressure lines. Conduct a pretest leak-check as follows for each venturi: (1) blow through the positive pressure line until at least 7.6 cm (3.0 in.) H₂O pressure registers on the manometer; then, close off the tubing. The pressure shall remain stable for at least 15 seconds; (2) do the same for the negative or low pressure side, except using suction to obtain the minimum of 7.6 cm (3.0 in.) H₂O. Other leak-check procedures, subject to the approval of the Administrator, may be used.

8.8 How do I operate the sample train?

You must maintain cut sizes at the cyclones of 10 microns and 2.5 microns and keep the isokinetics as close to 100% as possible. Maintain the probe and heated compartment temperatures at least 10°F greater than the stack gas temperature. Maintain the relative humidity of the dilution supply air at less than 50%. For each run, record the site barometric pressure (adjust for elevation) on a field test data sheet; record additional required data at the beginning and end of each time increment (dwell time). You perform the following procedures:

- 8.8.1 Preheating Operations. You must preheat the combined sampling head to within 10°C (18°F) of the stack temperature of the gas stream at the test location before beginning the test. You must preheat the probe and the sample venturi compartment to 5°C (9°F) higher than the stack gas temperature. This will prevent moisture from condensing from the sample gas stream.

- 8.8.1.1 *Unsaturated stacks.* You must complete a passive warmup (of 30 to 40 minutes) within the stack before the run begins to avoid internal condensation. [NOTE: Unsaturated stacks do not have entrained droplets and operate at temperatures above the local dew point of the stack gas.]
- 8.8.1.2 *Shortened warm-up of unsaturated stacks.* You can shorten the warmup time by heating outside the stack (such as by a heat gun). Then place the heated sampling head inside the stack and allow the temperature to equilibrate.

- 8.8.2 Sample Point Dwell Time. You must calculate the dwell time (that is, sampling time) for each sampling point to ensure that the overall run provides a velocity-weighted average that is representative of the entire gas stream. Vary the dwell time, or sampling time, at each traverse point proportionately with the sample traverse point velocity. Use the equations below to calculate the dwell time at the first point and at each subsequent point. It is recommended that the number of minutes sampled at each point be rounded to the nearest 15 seconds.
- 8.8.2.1 *Dwell time at first sampling point*. Calculate the dwell time for the first point, t_1 , using Equation 30. You must use the data from the preliminary traverse. N equals the total number of traverse points to be sampled.
- 8.8.2.2 *Dwell time at remaining sampling points*. Calculate the dwell time at each of the remaining traverse points, t_n , using Equation 31. This time you must use the actual test run data. [**NOTE:** Round the dwell times to 1/4 minutes.] Each traverse point must have a dwell time of at least two minutes.
- 8.8.3 Adjusted velocity pressure. When selecting your sampling points using your preliminary velocity traverse data, your preliminary velocity pressures must be adjusted to take into account the increase in velocity due to blockage. If necessary, you must adjust your preliminary velocity data for differences in pitot tube coefficients. Use the following instructions to adjust the preliminary velocity pressure.
- 8.8.3.1 *Different pitot tube coefficient*. You must use Equation 16 to correct the recorded preliminary velocity pressures if the pitot tube mounted on the combined cyclone sampling head has a different pitot tube coefficient than the pitot tube used during the preliminary velocity traverse.
- 8.8.3.2 *Probe blockage factor*. You must use Equation 17 to calculate an average probe blockage correction factor (b_p) if the diameter of your stack or duct is between 18 and 24 inches. A probe blockage factor is calculated because of the flow blockage caused by the relatively large cross-sectional

area of the combined cyclone sampling head, as discussed in Section 8.3.2 and illustrated in Figure 8 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method. [NOTE: The sampling head has a projected area of approximately 17 square inches when oriented into the gas stream. As the probe is moved from the most outer to the most inner point (towards the center of the stack), the amount of blockage that actually occurs ranges from approximately 4 square inches to the full 17 square inches. The average cross-sectional area blocked is approximately 10 square inches.]

8.8.3.3 *Final adjusted velocity pressure.* Calculate the final adjusted velocity pressure(Δp_{s2}) using Equation 18. [NOTE: Figure 8 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method illustrates that the blockage effect of the large combined cyclone sampling head increases rapidly below diameters of 18 inches. Therefore, you must follow the procedures outlined in Method 1A to conduct tests in small stacks (<18 inches diameter). You must conduct the velocity traverse downstream of the sampling location or immediately before the test run.]

8.8.4 Sample Train Operation. You must follow the procedures outlined in paragraph 4.1.5 of Method 201A of Appendix M to 40 CFR part 51 to operate the sample train.

8.8.4.1 *Portholes.* Clean the portholes prior to the test run. This will minimize the chance of collecting deposited material from the port in the nozzle.

8.8.4.2 *Sampling Procedures.* After preheating the sampling head and verifying that the probe and sample venturi compartment temperatures are within 5°C (9°F) of stack temperature, remove the protective cover from the nozzle. Position the probe at the first sampling point with the nozzle pointing directly into the gas stream. Ensure the probe/pitot tube assembly is leveled. [NOTE: When the probe is in position, block off the openings around the probe and porthole to prevent unrepresentative

dilution of the gas stream.] To begin sampling, adjust the motor control settings of each blower to reach the dilution ratio and sampling head cut sizes desired.

- 8.8.4.2.1 Startup. You must simultaneously start the dilution blower and exhaust blower. Adjust the dilution air supply rate by changing the motor control setting of the dilution blower until the pressure reading of the dilution venturi matches the target ΔH_2 calculated previously for the desired dilution ratio. Similarly, adjust the sampling rate by changing the motor control setting of the mixed/exhaust air blower until the pressure reading of the sample venturi matches the target ΔH_1 calculated previously for the desired particulate cut sizes. It is helpful to have an estimate of the motor control settings needed for the target dilution ratio and cut sizes before the test so that the settings may be quickly reached (to minimize the amount of test time not meeting the criteria of the method).
- 8.8.4.2.2 Traversing. You must traverse the stack cross-section, as required by Method 5 of Appendix A to 40 CFR part 60. Do not bump the cyclone nozzle into the stack walls when sampling near the walls or when removing or inserting the probe through the portholes. This will minimize the chance of extracting deposited materials.
- 8.8.4.2.3 Data Recording. You must either record the data required on the field test data sheet for each run or store the data electronically in a data acquisition system (DAS). If you record the data on field test data sheets, record the initial data readings. Then take readings at the following times: (1) the beginning and end of each sample time increment, (2) when changes in flow rates are made, and (3) when sampling is halted. Compare the velocity pressure measurements (Equations 28 and 29) with the velocity pressure measured during the preliminary traverse. Keep the sample venturi ΔH_1 at the value

calculated in Section 8.5.3 for the stack temperature that is observed during the test. Keep the dilution venturi ΔH_2 at the value calculated in Section 8.5.4. Record all the point-by-point data and other source test parameters on the field test data sheet. Maintain the flow through the sampling system until the last traverse point is sampled. Do not leak check the sampling system during port changes.

- 8.8.4.3 *End of Run Procedures.* Stop the blowers and remove the sampling train from the stack. Use care so that you do not scrape the pitot tube or the combined sampling head against the port or stack walls. Record the final readings and other test parameters on the field test data sheet. After you stop the gas flow, make sure you keep the cyclone head level to avoid tipping dust from one section of the sampling head to another. After cooling and when the probe can be safely handled, wipe off all external surfaces near the cyclone nozzle and cap the inlet to cyclone I. Remove the sampling head from the probe. Cap the nozzle and exit of cyclone IV to prevent particulate matter from entering the assembly.
- 8.8.4.4 *Post-Sampling Leak Check.* Leak check the non-diluted sampling train section as described in Section 8.7.1.1. after removing the combined cyclone head. Leak check the diluted sampling train section as described in Section 8.7.1.2. Conduct the leak checks at a vacuum of 3 inches (76 mm) Hg. Enter the results of the leak checks onto the field test data sheet. If the leak rate of the non-diluted sampling train section (without the combined cyclone sampling head) exceeds 0.02 cfm or 4% of the average sampling rate during the test run (whichever is less), the run is invalid and you must repeat it.

8.9 How do I recover particulate matter from the sample train?

Recovery involves the quantitative transfer by brushing and rinsing with acetone of particles in the following size ranges: (1) > 10 micrometers, (2) ≤ 10 micrometers but > 2.5

micrometers, and (3) ≤ 2.5 micrometers. You must use a Nylon or Teflon[®] bristle brush and ultra-pure acetone rinse to recover particles from the nozzle, cyclone heads, probe, sample venturi, mixing cone, residence chamber, and front half of the filter holder. Sample recovery should take place in a clean environment and not on the stack.

- 8.9.1 Container No. 1 (Nozzle and Cyclone I Particulate > 10 micrometers) - This particulate size fraction recovery is optional. Quantitatively recover the (1) particulate matter from the cyclone I cup and acetone rinses (and brush cleaning) of the cyclone I cup, (2) internal surface of the nozzle, and (3) cyclone I internal surfaces, including the inside surface of the downcomer line, into Container No. 1. Seal the container and mark the liquid level on the outside of the container. You must keep any dust found on the outside of cyclone I and cyclone nozzle external surfaces out of the sample. This container holds particulate matter > 10 micrometers.
- 8.9.2 Container No. 2 (Cyclones I and IV Particulate ≤ 10 and > 2.5 micrometers) - This particulate size fraction is optional. Place in Container No. 2 the solids from the cyclone IV cup and the acetone (and brush cleaning) rinses of the cyclone I turnaround cup (above inner downcomer line), cyclone I exit tube, and cyclone IV excluding the exit tube interior surface. Seal the container and mark the liquid level on the outside of the container. This container holds “coarse” particulate matter (≤ 10 and > 2.5 micrometers).
- 8.9.3 Container No. 3 (Cyclone IV, Probe, Sample Venturi, Mixing Cone, Residence Chamber, and Filter Holder Inlet Particulate ≤ 2.5 micrometers) - Rinse, brush, and recover all the remaining interior surfaces exposed to the sample gas in Container No. 3. This will include all components from the exit tube of cyclone IV up to and including the filter holder inlet (142 mm). Specific components are the exit tube of cyclone IV, probe, sample venturi, sample venturi cone connector, mixing cone, residence chamber, and the front half (inlet) of the filter holder. Seal the container and mark the liquid level on the outside of the container. This container holds particulate matter that is ≤ 2.5 micrometers.

- 8.9.4 Container No. 4 (Filter Particulate ≤ 2.5 micrometers) - Use tweezers and/or clean disposable surgical gloves to remove the filter from the filter holder. Place the filter in its filter cassette or other clean protective container (e.g., the petri dish or wax paper sleeve) you identified as Container No. 1. Using a dry Nylon or Teflon[®] bristle brush and/or a sharp-edged blade, carefully transfer any particulate matter and/or filter fibers that adhere to the filter holder gasket or filter support screen to the petri dish or wax sleeve. Seal the container. This container holds particles ≤ 2.5 micrometers.
- 8.9.5 Container No. 5 (Acetone Blank) - Take 50 ml of the acetone directly from the wash bottle you used, and place it in Container No.5, labeled Acetone Rinse Blank.

8.10 How do I store and transport the samples?

During transport to the laboratory, the filters should be placed in their cassettes or other protective containers. Any protective containers that protect the filters from contamination may be used. The protective container may be appropriately sized so that the collected sample does not directly touch the interior surface of the container. Samples, accompanied by the completed chain of custody record, can be packed in an insulated protective container (a cooler for example) with as many containers of frozen ice substitute as needed to keep the samples cool during the transport period (see validation guidance in Section 9.5 of this method). The temperature inside the transport container can be monitored with a maximum/minimum thermometer or other indicator of temperature, especially of maximum temperature. Package and handle the samples in a manner that reduces vibrations than may dislodge particles from the filters. Upon arrival at the laboratory, the samples may be stored in a refrigerator at approximately 4°C (39°F) or less until the start of the conditioning period.

9. QUALITY CONTROL

9.1 What do I use to perform daily quality audits?

Conduct daily quality audits using data quality indicators that require review of (1) recording and transfer of raw data, (2) calculations, and (3) documentation of testing procedures.

9.2 How do I verify the calculations?

Verify the calculations by independent, manual checks. You must flag any suspect data and identify the nature of the problem and potential effect on data quality. After you complete the test, prepare a data summary and compile all the calculations and raw data sheets.

9.3 When must I record operating conditions?

You must record any unusual process operating conditions or adverse weather conditions that occur during testing. Discontinue the test if the operating conditions may cause non-representative particulate emissions.

9.4 When must I develop a health and safety plan?

You must develop a health and safety plan to ensure the safety of your employees who are on-site conducting the test. Your plan must conform with all applicable OSHA, MSHA, and DOT regulatory requirements. The procedures must also conform to the plant health and safety requirements.

9.5 How do I minimize contamination of and preserve the sample collected on the filter?

Because the filter samples are collected at ambient temperatures, you must take precautions to keep the filters from experiencing temperatures higher than the filtration temperatures that may cause the release of captured semivolatile particulate. Validation of samples for post-collection transport and weighing may be based on the following guidance which is loosely based on the EPA Ambient PM_{2.5} STN guidelines:

- The elapsed time clock starts at the end of the sample period.

- Upon removal of the filter from the sampler, the filter is inserted into a clean, protective container, which is placed in the filter transport container with appropriate cooling.
- A minimum/maximum thermometer or alternative method of monitoring the filter temperature and recording the maximum filter temperature, such as a liquid crystal temperature sensor strip, is reset and put it in the transport container to monitor filter temperature during transport.

9.5.1 Filter Handling Procedures. You must follow the procedures below, documenting the transfer of the custody of the filters on chain of custody forms.

- 9.5.1.1 Include enough coolant packages or other cooling means in the transport container to maintain filters as cool as practical; but at 25°C (77°F) or less during transport.
- 9.5.1.2 Transport the filters in the transport container to the laboratory expeditiously.
- 9.5.1.3 Upon arrival at the lab, verify from the minimum/maximum thermometer (or alternative temperature monitor) that the filter temperature has been maintained at 25°C (77°F) or less.
- 9.5.1.4 Note the sample end date and determine the 10-day post-weigh deadline.
- 9.5.1.5 Transfer the filters to a refrigerator maintained at 4°C (39°F) or lower for storage until the beginning of the conditioning period.
- 9.5.1.6 Complete the required post-sampling conditioning period and weighing as soon as practical but not later than the 10-day deadline.

9.5.2 Rinse Samples Handling Procedures. You must follow the procedures below, documenting the transfer of the custody of the rinse samples on chain of custody forms.

- 9.5.2.1 Package the samples in a manner to prevent breakage during transport.
- 9.5.2.2 Promptly transfer the rinse containers in the transport container to the laboratory.

- 9.5.2.3 Upon arrival at the lab, verify that no leakage of samples from the containers has occurred.
- 9.5.2.4 Transfer the samples to a refrigerator maintained at 4°C (39°F) or lower for storage until the beginning of the evaporation of the samples.

10. CALIBRATION AND STANDARDIZATION

[NOTE: Maintain a laboratory log of all calibrations.]

10.1 How do I calibrate and use S-type pitots to measure the stack gas flow velocities?

Measure the gas flow velocities at the sampling locations using Method 2 of Appendix A to 40 CFR part 60. You must use an S-type pitot tube that meets the required EPA specifications (EPA Publication 600/4-77-0217b) during these velocity measurements. You must also:

- (a) Visually inspect the S-type pitot tube before sampling.
- (b) Leak check both legs of the pitot tube before and after sampling.
- (c) Maintain proper orientation of the S-type pitot tube while making measurements.

10.1.1 S-type pitot tube orientation. The S-type pitot tube is oriented properly when the yaw and the pitch axis are 90 degrees to the air flow.

10.1.2 Average velocity pressure record. Instead of recording either high or low values, record the average velocity pressure at each point during flow measurements.

10.1.3 Pitot tube coefficient. Determine the pitot tube coefficient based on physical measurement techniques described in Method 2 of Appendix A to 40 CFR part 60. [Otherwise, you must calibrate the pitot tube on the sampling head because of potential interferences from the cyclone body.]

10.2 What procedures must I follow to calibrate the temperature measurement system (i.e., temperature sensor)?

You must use the procedures described in paragraph 10.3 of Method 2 of Appendix A to 40 CFR part 60 to calibrate the temperature measurement system. Check each temperature sensor at a minimum of three points over the anticipated range of use against an NIST-traceable mercury-in-glass thermometer or a thermocouple simulator.

10.3 What types of nozzles must I use for sampling?

Use electropolished stainless steel (316 or equivalent) or Teflon[®]-coated nozzles for isokinetic sampling. Make sure that all nozzles are thoroughly cleaned, visually inspected, and calibrated according to the procedure outlined in paragraph 10.1 of Method 5 of Appendix A to 40 CFR part 60.

10.4 What procedures must I follow to calibrate the sample and dilution venturis?

You must calibrate the each venturi over the expected range of flow rates to be encountered. For the sample venturi, this will be 0.35 to 0.45 standard cfm or 0.35 to 1.0 actual cfm; for the dilution venturi, this will be 3.6 to 20 actual cfm. Each venturi should be fabricated so that the typical pressure differentials are in the optimal operating range of the devices used to monitor the pressures. Because of the wide range of expected dilution air supply flow rates, a single dilution venturi is not practical. It is recommended that you have a 1/2-inch and a 5/8-inch venturi calibrated and available for use.

10.4.1 Sample Venturi Calibration. You must calibrate the sample venturi using procedures similar to those in EPA Method 5 for calibrating the meter orifice using a dry gas meter. You must generate a curve of pressure versus flow rate and calculate a trend line power curve equation.

10.4.2 Dilution Venturi Calibration. You must calibrate the sample venturi using procedures similar to those in EPA Method 5 for calibrating the meter orifice but using a Roots meter instead of a dry gas meter. You must generate a curve of pressure versus flow rate and calculate a trend line power curve equation.

10.5 What procedures must I follow to calibrate the relative humidity transmitters?

You may use the manufacturers calibration information for the relative humidity (RH) sensors. Because it is the difference between the two RH sensors that is important, it is necessary that the two RH sensors agree when monitoring the same gas stream.

11. ANALYTICAL PROCEDURES

11.1 What procedures must I follow to record analytical data?

Record all data on the analytical data sheet. You can obtain the data sheet from Figure 5-6 of Method 5 of Appendix A to 40 CFR part 60.

11.2 What procedure must I follow for the container analysis?

Follow the analysis procedures outlined below:

- 11.2.1 Container Nos. 1, 2, 3, and 5. Note the level of liquid in the container, and confirm on the analysis sheet whether leakage occurred during transport. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Measure the liquid in this container either volumetrically to ± 1 ml or gravimetrically to ± 0.5 g. Transfer the contents to a tared aluminum pan, and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours, and weigh to a constant weight. For the purposes of this section, the term "constant weight" means a difference of no more than 0.05 mg or 1 percent of total weight less tare weight, whichever is greater, between two consecutive weighings, with no less than 6 hours of desiccation time between weighings. Report the results to the nearest 0.01 mg.
- 11.2.2 Container No. 4. Leave the contents in the shipping container or transfer the filter and any loose PM from the sample container to a tared glass weighing dish. Desiccate for 24 hours in a desiccator containing anhydrous calcium sulfate.

Desiccate to a constant weight, and report the results to the nearest 0.01 mg.

Constant weight is defined the same as above.

12. CALCULATIONS AND DATA ANALYSIS

12.1 What do I need to calculate?

You need to perform all of the calculations found in Table 3 of this paragraph. Table 3 also provides instructions and references for the calculations.

**Table 3. Calculations for Actual Test Run Conditions
and Recovery of PM_{10} and $PM_{2.5}$**

Calculations	Instructions and References
Mixed gas blower pressure, absolute (P_3)	Use Equation 32
Sample venturi gas pressure, absolute (P_1)	Equation 33
Dilution venturi air pressure, absolute (P_2)	Equation 34
Water vapor pressure of dilution air, absolute (P_{v_2})	Equation 35
Water vapor pressure of mixed gas, absolute (P_{v_3})	Equation 36
Molecular weight of dilution air (M_2)	Equation 37
Molecular weight of mixed gas (M_3)	Equation 38
Sampling rate at actual conditions (Q_1)	Equation 39
Gas sampling rate at stack conditions through cyclones I (Q_S)	Recalculate Q_S with Equation 40 using actual temperatures and pressures measured during each run.
Dilution air flow rate at venturi (Q_2)	Equation 41

**Table 3. Calculations for Actual Test Run Conditions
and Recovery of PM₁₀ and PM_{2.5}**

Calculations	Instructions and References
Mixed gas flow rate at ambient conditions (Q_{33})	Equation 42
Mixed gas water vapor flow rate Diluted (Q_{W33})	Equation 43
Dilution air water vapor flow rate (Q_{W22})	Equation 44
Sample gas water vapor flow rate at mixed conditions (Q_{WS3})	Equation 45
Dilution air flow rate at dry standard conditions ($Q_{d(std)}$)	Equation 46
Sample gas flow rate at dry standard conditions ($Q_{S(std)}$)	Equation 47
Moisture content of stack gas (B_{ws})	Equation 48
Dilution ratio (R)	Equation 49
Gas viscosity (μ)	Recalculate viscosity using Equation 3 using actual stack temperature, moisture, and oxygen content.
Actual particle cut diameter for cyclone I (D_{50})	Calculate this using Equation 50 and using the average temperatures and pressures measured during each test run.
Test condition Reynolds number	Use Equation 8 to calculate the actual Reynolds number during test conditions based on: (1) the sampling rate for the combined cyclone head, (2) the actual gas viscosity for the test, and (3) the dry and wet gas stream molecular weights.
Cunningham correction factor (C_r)	Recalculate the Cunningham correction factor using Equation 53 using actual test run data and a D_p of 2.5.

**Table 3. Calculations for Actual Test Run Conditions
and Recovery of PM₁₀ and PM_{2.5}**

Calculations	Instructions and References
Particle cut diameter for $N_{re} < 3162$ for cyclone IV (D_{50})	Depending on the N_{re} value, use Equation 51 or 52 and the recalculated Cunningham factor (C_r) to recalculate the particle cut diameter.
or	
Particle cut diameter for $N_{re} \geq 3162$ for cyclone IV (D_{50}) of 2.5	
Re-establish cyclone IV D_{50} (D_{50-1})	Use Equations 53 or 54 to recalculate the particle cut diameter. Use the re-established Cunningham correction factor (calculated in the previous step) and the calculated Reynold's number to determine D_{50-1} .
Establish "Z" values. The "Z" value is the result of an analysis that you must perform to determine if the Cunningham correction factor is acceptable.	Use Equation 56 to establish "Z" values. Compare the calculated cyclone IV D_{50} (either Equation 51 or 52) to the re-established cyclone IV D_{50-1} (either Equation 54 or 55) values based upon the test condition calculated Reynolds number. Acceptable "Z" value is determined by Equation 57.
Volume sampled, dry SCF ($V_{s(std)}$)	Use Equation 58.
Percent isokinetic rate (I)	Calculate this with Equation 59.
Acetone blank concentration (C_a)	Calculate this with Equation 60
Acetone blank weight (W_a)	Calculate this with Equation 61
Concentration of PM _{2.5} particulate matter ($C_{PM2.5}$)	Calculate this with Equation 62
Concentration of coarse particulate matter < 10 and ≥ 2.5 μm ($C_{PM10-2.5}$)	Calculate this with Equation 63
Concentration of collectible PM ₁₀ matter (C_{PM10})	Calculate this with Equation 64

**Table 3. Calculations for Actual Test Run Conditions
and Recovery of PM₁₀ and PM_{2.5}**

Calculations	Instructions and References
Concentration of particulate matter > 10 μm ($C_{\text{PM}>10}$)	Calculate this with Equation 65
Concentration of total collectible particulate matter (C_{PMTotal})	Calculate this with Equation 66

12.1.1 Gas Pressure in Sampling Train.

12.1.1.1 *Mixed Air RH Sensor Gas Pressure.* Calculate the mixed gas absolute pressure at the RH sensor (P_3) using Equation 32.

12.1.1.2 *Sample Venturi Gas Pressure.* Calculate the sample venturi gas absolute pressure (P_1) using Equation 33.

12.1.1.3 *Dilution Venturi Air Pressure.* Calculate the dilution venturi air absolute pressure (P_2) using Equation 34.

12.1.1.4 *Water Vapor Pressure of Dilution Air.* Calculate the water vapor absolute pressure of the dilution (P_{v2}) air on an absolute basis using Equation 35.

12.1.1.5 *Water Vapor Pressure of Mixed Gas.* Calculate the water vapor absolute pressure of the mixed gas (P_{v3}) using Equation 36.

12.1.2 Molecular Weight of Dilution Air and Mixed Gas.

12.1.2.1 *Molecular Weight of Dilution Air, Wet.* Calculate the molecular weight of the dilution air (M_2) using Equation 37.

12.1.2.2 *Molecular Weight of Mixed Gas.* Calculate the molecular weight of the mixed gas (M_3) (i.e., sample gas mixed with dilution air) using Equation 38.

12.1.3 Gas Flow Rates.

12.1.3.1 *Sampling Flow Rate at Actual Conditions.* Calculate the sampling flow rate (Q_1) at actual conditions using Equation 39.

- 12.1.3.2 *Sampling Flow Rate at Cyclones.* Calculate the sampling flow rate through the Cyclones (Q_S) at actual conditions using Equation 40.
- 12.1.3.3 *Dilution Air Flow Rate at Ambient Conditions.* Calculate the dilution air flow rate (Q_2) at ambient conditions using Equation 41.
- 12.1.3.4 *Mixed Gas Flow Rate at Ambient Conditions.* Calculate the mixed gas flow rate at ambient conditions (Q_{33}) using Equation 42.
- 12.1.3.5 *Mixed Gas Water Vapor Flow Rate.* Calculate the mixed gas water vapor flow rate (Q_{W33}) using Equation 43.
- 12.1.3.6 *Dilution Air Water Vapor Flow Rate.* Calculate the dilution air water vapor flow rate (Q_{W22}) using Equation 44.
- 12.1.3.7 *Sample Gas Water Vapor Flow Rate at Mixed Conditions.* Calculate the sample gas water vapor flow rate (Q_{WS3}) using Equation 45.
- 12.1.3.8 *Dilution Air Flow Rate at Dry Standard Conditions.* Calculate the dilution air flow rate ($Q_{d(std)}$) at dry standard conditions using Equation 46.
- 12.1.3.9 *Sample Gas Flow Rate at Dry Standard Conditions.* Calculate the dilution air flow rate ($Q_{S(std)}$) at dry standard conditions using Equation 47.
- 12.1.4 Moisture Content. Calculate the moisture content of the stack gas (B_{ws}) using Equation 48.
- 12.1.5 Dilution Ratio. Calculate the dilution ratio (DR) using Equation 49.
- 12.1.6 D_{50} of cyclone IV. You must analyze D_{50} of cyclone IV and the concentrations of the particulate matter in the various size ranges. To determine the actual D_{50} for cyclone IV, you must recalculate the Cunningham correction factor and the Reynolds number for the best estimate of cyclone IV D_{50} . The following paragraphs summarize additional information on how to recalculate the Cunningham correction factor and determine which Reynold's number to use.
 - 12.1.6.1 *Cunningham correction factor.* You must recalculate the initial estimate of the Cunningham correction factor using the actual test data. Insert the actual test run data and D_{50} of 2.5 micrometers into Equation 53. This

will give you a new Cunningham correction factor that is based on actual data.

- 12.1.6.2 *Initial D_{50} for cyclone IV.* Determine the initial estimate for cyclone IV D_{50} using the test condition Reynolds number calculated with Equation 9 as indicated in Table 3 of this section. Refer to the following instructions.
- (a) If the Reynold's number is less than 3162, calculate the D_{50} for cyclone IV with Equation 51, using actual test data.
 - (b) If the Reynold's number is equal to or greater than 3162, calculate the D_{50} for cyclone IV with Equation 52, using actual test data.
 - (c) Insert the "new" D_{50} value calculated by either Equation 51 or 52 into Equation 53 to re-establish the Cunningham Correction Factor (C_r).
- [NOTE: Use the test condition calculated Reynolds number to determine the most appropriate equation (Equation 51 or 52).]
- 12.1.6.3 *Re-establish cyclone IV D_{50} .* Use the re-established Cunningham correction factor (calculated in the previous step) and the calculated Reynold's number to determine D_{50-1} .
- (a) Use Equation 54 to calculate the re-established cyclone IV D_{50-1} if the Reynolds number is less than 3162.
 - (b) Use Equation 55 to calculate the re-established cyclone IV D_{50-1} if the Reynolds number is equal to or greater than 3162.
- 12.1.6.4 *Establishing "Z" values.* The "Z" value is the result of an analysis that you must perform to determine if the Cunningham correction factor is acceptable. Compare the calculated cyclone IV D_{50} (either Equation 51 or 52) to the re-established cyclone IV D_{50-1} (either Equation 54 or 55) values based upon the test condition calculated Reynolds number (Equation 56). Follow these procedures:
- (a) Use Equation 56 to calculate the "Z". If the "Z" value is within 0.99 and 1.01, then the D_{50-1} value is the best estimate of the cyclone IV D_{50} cut diameter for your test run.

- (b) If the “Z” value is greater than 1.01 or less than 0.99, re-establish a Cunningham correction factor based on the D_{50-1} value determined in either Equations 54 or 44, depending upon the test condition Reynolds number.
- (c) Use the second revised Cunningham correction to re-calculate the cyclone IV D_{50} .
- (d) Repeat this iterative process as many times as necessary using the prescribed equations until you achieve the criteria documented in Equation 57.

12.1.7 Particulate Concentration. Use the particulate catch weights from the sampling train (including any particulate catch weights from speciation train components) to calculate the concentration of particulate matter in the various size ranges. You must correct the catch weights for the acetone blank.

12.1.7.1 *Acetone blank concentration.* Use Equation 60 to calculate the acetone blank concentration (C_a).

12.1.7.2 *Acetone blank weight.* Use Equation 61 to calculate the acetone blank weight (W_a).

12.1.7.3. *Particulate weight catch per size fraction.* Subtract the weight of the acetone blank from the particulate weight catch in each size fraction that used acetone in the recovery. [NOTE: Do not subtract a blank value of greater than 0.001 percent of the weight of the acetone used from the sample weight.] Use the following procedures.

- (a) Use Equation 62 to calculate the concentration of $PM_{2.5}$ particulate ($C_{PM2.5}$) recovered quantitatively from Container Nos. 3 and 4.
- (b) Use Equation 63 to determine the concentration of coarse particulate from the quantitative recovery of $PM_{<10>2.5}$ particulate matter ($C_{PM<10>2.5}$) from Container No. 2.
- (c) Use Equation 64 to calculate the concentration of PM_{10} particulate (C_{PM10}) recovered quantitatively from Container Nos. 2, 3, and 4.

- (d) Use Equation 65 to calculate the concentration of particulate > 10 micrometers quantitatively recovered from Container No. 1.
- (e) Use Equation 66 to calculate the total particulate matter concentration of all of the particulate from Container Nos. 1, 2, 3, and 4. This is the total collectable particulate matter concentration (C_{total}).

12.2 What must I include in the emissions test report?

You must include the following list of conventional elements in the emissions test report.

- (a) Emission test description including any deviations from this protocol
- (b) Summary data tables on a run-by-run basis
- (c) Flowchart of the process or processes tested
- (d) Sketch of the sampling location(s)
- (e) Preliminary traverse data sheets including cyclonic flow checks
- (f) Raw field data sheets
- (g) Laboratory analytical sheets and case narratives
- (h) Sample calculations
- (i) Pretest and post-test calibration data
- (j) Chain of custody forms
- (k) Documentation of process and air pollution control system data

12.3 What nomenclature do I use in this method?

You must use the following nomenclature:

- A = Area of stack or duct at sampling location, square inches.
- A_n = Area of nozzle, square feet.
- b_f = Average blockage factor calculated in Equation 17, dimensionless.
- B_{ws} = Moisture content of gas stream, fraction
(e.g. 10% H_2O is $B_{ws} = 0.10$).
- C = Cunningham correction factor for particle diameter, D_p , and calculated using the actual stack gas temperature, dimensionless.

$\%CO_2$	= Carbon dioxide content of gas stream, % by volume.
C_a	= Acetone blank concentration, mg/mg.
C_{PM10}	= Concentration of PM_{10} particulate matter, gr/DSCF.
$C_{PM>10}$	= Concentration of particulate matter > 10 microns, gr/DSCF.
$C_{PM<10>2.5}$	= Concentration of coarse particulate matter between 10 and 2.5 microns, gr/DSCF.
$C_{PM2.5}$	= Concentration of $PM_{2.5}$ particulate matter, gr/DSCF.
C_p	= Pitot coefficient for the combined cyclone pitot, dimensionless.
C_p'	= Coefficient for the pitot used in the preliminary traverse, dimensionless.
$C_{PMTotal}$	= Concentration of total collectable particulate matter, gr/DSCF.
C_r	= Re-estimated Cunningham correction factor for particle diameter equivalent to the actual cut size diameter and calculated using the actual stack gas temperature, dimensionless.
C_1	= -150.3162 (micropoise)
C_2	= 18.0614 (micropoise/ $K^{0.5}$) = 13.4622 (micropoise/ $R^{0.5}$)
C_3	= 1.19183×10^6 (micropoise K^2) = 3.86153×10^6 (micropoise R^2)
C_4	= 0.591123 (micropoise)
C_5	= 91.9723 (micropoise)
C_6	= 4.91705×10^{-5} (micropoise/ K^2) = 1.51761×10^{-5} (micropoise/ R^2)
D_n	= Inner diameter of sampling nozzle mounted on cyclone I or IV, inches.
D_p	= Physical particle size, micrometers.

D_{50}	= Particle cut diameter, micrometers.
D_{50-1}	= Re-calculated particle cut diameters based on re-estimated C_r , micrometers.
D_{50LL}	= Cut diameter for cyclone I corresponding to the 2.25 micrometer cut diameter for cyclone IV, micrometers.
D_{50n}	= D_{50} value for cyclone IV calculated during the Nth iterative step, micrometers.
$D_{50(n+1)}$	= D_{50} value for cyclone IV calculated during the N+1 iterative step, micrometers.
D_{50t}	= Cyclone I cut diameter corresponding to the middle of the overlap zone shown in Figure 9 of the Tables, Diagrams, Flowcharts, and Validation Data section of this method, micrometers.
DR	= Dilution Ratio, dimensionless.
I	= Percent isokinetic sampling, dimensionless.
k_1	= coefficient for sample venturi flow rate equation (Equation 13), dimensionless.
k_2	= coefficient for dilution venturi flow rate equation (Equation 14), dimensionless.
K_p	= 85.49, [(ft/sec)/(pounds/mole -°R)].
m_a	= Mass of residue of acetone blank after evaporation, mg.
m_f	= Mass of particulate matter (mg) collected on the filter, ≤ 2.5 micrometers.
m_1	= Mass of particulate matter (mg) recovered from Container No. 1 (acetone blank corrected), optional, >10 micrometers, optional.
m_2	= Mass of particulate matter (mg) recovered from Container No. 2 (acetone blank corrected), optional, ≤ 10 and >2.5 micrometers, optional.
m_3	= Mass of particulate matter (mg) recovered from Container No. 3 (acetone blank corrected), ≤ 2.5 micrometers.

$M_{1\text{est}}$	=	Estimated molecular weight of wet gas at sample venturi, pounds/pound mole.
M_1	=	Calculated molecular weight of wet gas at sample venturi, pounds/pound mole.
$M_{2\text{est}}$	=	Estimated molecular weight of wet gas at dilution venturi, pounds/pound mole.
M_2	=	Calculated molecular weight of wet gas at dilution venturi, pounds/pound mole.
M_3	=	Molecular weight of wet gas at mixing tube, pounds/pound mole.
M_d	=	Molecular weight of dry stack gas, pounds/pound mole.
M_w	=	Molecular weight of wet stack gas, pounds/pound mole.
n_1	=	Exponent for sample venturi flow rate equation (Equation 13), dimensionless.
n_2	=	Exponent for dilution venturi flow rate equation (Equation 14), dimensionless.
N	=	Number of iterative steps or total traverse points.
N_{re}	=	Reynolds number, dimensionless.
$\%O_{2,\text{wet}}$	=	Oxygen content of gas stream, % by volume of wet gas.

[NOTE: the oxygen percentage used in Equation 3 is on a WET gas basis; that means that since O_2 is typically measured on a dry gas basis, the measured $\%O_2$ must be multiplied by the quantity $(1 - B_{ws})$ to convert to the actual volume fraction.
Therefore $\%O_{2,\text{wet}} = (1 - B_{ws}) * \%O_{2\text{dry}}$]

$P_{1\text{est}}$	=	Estimated absolute sample venturi gas pressure, in. Hg.
P_1	=	Calculated absolute sample venturi gas pressure, in. Hg.
$P_{2\text{est}}$	=	Estimated absolute dilution venturi gas pressure, in. Hg.
P_2	=	Calculated absolute dilution venturi gas pressure, in. Hg.

P_3	=	Calculated absolute mixing chamber gas pressure, in. Hg.
P_b	=	Barometric pressure, in. Hg.
P_g	=	Gauge stack gas pressure, in H_2O .
P_s	=	Absolute stack gas pressure, in. Hg.
P_{v2}	=	Absolute water vapor pressure @ dilution venturi, in. Hg.
P_{v3}	=	Absolute water vapor pressure @ exhaust air, in. Hg.
$Pump_g$	=	Static pressure (gauge) of dilution pump, in. Hg.
Q_1	=	Sampling flow rate, ACFM wet.
Q_2	=	Dilution flow rate, ACFM wet.
Q_{33}	=	Mixed gas flow rate, ACFM wet.
$Q_{d(std)}$	=	Dilution air flow rate, SCFM dry.
$Q_{dw(std)}$	=	Target dilution air flow rate based on assumed dilution ratio, wet, SCFM (Equation 12).
Q_s	=	Sample flow rate at cyclone I to achieve specified D_{50} , wet, ACFM.
$Q_{s(std)}$	=	Sample flow rate (standard conditions), SCFM dry.
$Q_{sw(std)}$	=	Sample flow rate (standard conditions), SCFM wet.
Q_I	=	Sampling rate for cyclone I to achieve specified D_{50} , ACFM wet.
Q_{w33}	=	Mixed Air Water Vapor Flow Rate.
Q_{w22}	=	Dilution Air Water Vapor Flow Rate.
Q_{ws3}	=	Water Vapor Flow Rate From Sample @ Mixed Conditions.
R_{max}	=	Nozzle/stack velocity ratio parameter, dimensionless.
R_{min}	=	Nozzle/stack velocity ratio parameter, dimensionless.
RH_{dil}	=	Relative humidity of dilution air, % full scale.

RH_{mix}	=	Relative humidity of mixed air, % full scale.
t_1	=	Sampling time at point 1, minutes.
t_n	=	Sampling time at point n, minutes.
t_r	=	Total projected run time, minutes.
T_1	=	Measured absolute sample venturi gas temperature ($^{\circ}R$).
T_2	=	Measured absolute dilution venturi air temperature at dilution blower RH sensor ($^{\circ}R$).
T_3	=	Absolute temperature of gas at mixed air blower RH sensor (i.e., mixed stack gas and dilution air) ($^{\circ}R$).
T_{dil}	=	Absolute air temperature at dilution blower RH sensor ($^{\circ}R$).
T_{mix}	=	Absolute temperature of gas at mixed air blower RH sensor ($^{\circ}R$).
T_s	=	Absolute stack gas temperature ($^{\circ}R$).
T_{sv}	=	Measured absolute sample venturi gas temperature ($^{\circ}R$).
v_{max}	=	Maximum gas velocity calculated from Equations 26 or 27, ft/sec.
v_{min}	=	Minimum gas velocity calculated from Equations 24 or 25, ft/sec.
v_n	=	Sample gas velocity in the nozzle, ft/sec.
v_s	=	Velocity of stack gas, ft/sec.
V_a	=	Volume of acetone blank, mL.
V_{aw}	=	Volume of acetone used in sample recovery, mL.
V_n	=	Velocity of air flow in the nozzle
$V_{s(std)}$	=	Volume of stack gas sampled, SCF dry.
V_{ws}	=	Volume of water vapor, SCF.
W_a	=	Weight of residue in sample contributed by acetone blank, mg.

W.C.	=	Water column.
Z	=	Ratio between estimated cyclone IV D_{50} values, dimensionless.
ΔH_1	=	Sample venturi pressure drop, in. W.C.
ΔH_2	=	Dilution venturi pressure drop, in. W.C.
$[(\Delta p)^{0.5}]_{\text{avg}}$	=	Average of square roots of the velocity pressures measured during the preliminary traverse, in. W.C.
Δp_m	=	Observed stack gas velocity pressure using S-type pitot tube in preliminary traverse, in. W.C.
Δp_{max}	=	Maximum stack gas velocity pressure, in. W.C.
Δp_{min}	=	Minimum stack gas velocity pressure, in. W.C.
Δp_n	=	Stack gas velocity pressure measured at point n during the test run, in. W.C.
Δp_s	=	Stack gas velocity pressure calculated in Equation 16, in. W.C.
Δp_{s1}	=	Stack gas velocity pressure adjusted for combined cyclone pitot tube, in. W.C.
Δp_{s2}	=	Stack gas velocity pressure corrected for blockage, in. W.C.
Δp_1	=	Stack gas velocity pressure measured at point 1, in. W.C.
μ	=	Gas viscosity, micropoise.
ρ_a	=	Density of acetone, mg/mL (see label on bottle).
10.0	=	Constant calculated as 60% of 17 square inch cross-sectional area of combined cyclone head, square inches.

12.4 What equations will I use in this method?

You will use the following equations to complete the calculations required in this test method. You will need to perform some calculations prior to the test (e.g., pretest calculations), during the test, and after the test (e.g., post-test).

12.4.1. PreTest Calculations. The following calculations must be performed prior to the test in order to determine appropriate sampling and dilution supply rates for the test.

Molecular Weight of Dry Stack Gas. This equation is similar to the equation in Method 201A of Appendix M to 40 CFR part 51.

$$M_d = 0.44 (\%CO_2) + 0.32(\%O_2) + 0.28 (100 - \%O_2 - \%CO_2) \quad \text{Equation 1}$$

[NOTE: Use estimated %CO₂ and %O₂ to calculate initial M_d prior to the test run.]

Molecular Weight of Wet Stack Gas. This equation is identical to the equation shown in Method 201A of Appendix M to 40 CFR part 51.

$$M_w = M_d (1 - B_{ws}) + 18 (B_{ws}) \quad \text{Equation 2}$$

[NOTE: For these initial calculations, you must either assume a moisture content (based on prior knowledge of the process); estimate moisture following the procedures outlined in EPA Method 4 in 40 CFR 60, Appendix A; use a wet bulb-dry bulb measurement device; or use a hand-held hygrometer measurement device for stack gas temperatures less than 160°F.)]

Gas Viscosity. This equation uses gas temperatures in °R, while the equation shown in Method 201A of Appendix M to 40 CFR part 51 had constants intended for gas temperatures expressed in °F.

$$\mu = C_1 + C_2 \sqrt{T_s} + C_3 T_s^{-2} + C_4 (\%O_{2, \text{wet}}) - C_5 B_{ws} + C_6 B_{ws} T_s^2 \quad \text{Equation 3}$$

[NOTE: This equation is identical to the equation shown in previous versions of Method 201A of Appendix M to 40 CFR part 51 with the exception that the constants are used for gas temperatures in °R, while the equation shown in Method 201A of Appendix M to 40 CFR part 51 had constants intended for gas temperatures expressed in °F. The latest released version of Method 201A of Appendix M to 40 CFR part 51 has a viscosity equation that predicts values within 0.5% of Equation 3.

Stack Gas Pressure (absolute)

$$P_s = P_b + \frac{P_s}{13.6} \quad \text{Equation 4}$$

Cunningham Correction Factor. The Cunningham correction factor is calculated for a 2.25 micrometer diameter particle. Assume that $D_p = 2.25$.

$$C = 1 + 0.0057193 \left[\frac{\mu}{P_s D_p} \right] \left[\frac{T_s}{M_w} \right]^{0.5} \quad \text{Equation 5}$$

Lower Limit Cut Diameter for Cyclone I for $N_{re} < 3162$. The Cunningham correction factor is for a 2.25 micrometer diameter particle.

$$D_{50LL} = 9.507 C^{0.3007} \left[\frac{M_w P_s}{T_s} \right]^{0.1993} \quad (N_{re} < 3162) \quad \text{Equation 6}$$

Cut Diameter for Cyclone I for the Middle of the Overlap Zone.

$$D_{50t} = \left(\frac{11 + D_{50LL}}{2} \right) \quad \text{Equation 7}$$

Target Sampling Rate through Cyclone I (at stack conditions, wet basis).

$$Q_s = Q_i = 0.07296(\mu) \left[\frac{T_s}{M_w P_s} \right]^{0.2949} \left[\frac{1}{D_{50t}} \right]^{1.4102} \quad \text{Equation 8}$$

Reynolds Number.

$$N_{re} = 8.64 \times 10^5 \left[\frac{P_s M_w}{T_s} \right] \left[\frac{Q_s}{\mu} \right] \quad \text{Equation 9}$$

Lower Limit Cut Diameter for Cyclone I for $N_{re} \geq 3162$. The Cunningham correction factor is for a 2.25 micrometer diameter particle.

$$D_{50LL} = 10.0959 C^{0.4400} \left[\frac{M_w P_s}{T_s} \right]^{0.0600} \quad (N_{re} \geq 3162) \quad \text{Equation 10}$$

Target Sampling Rate through Cyclone I (at standard conditions, wet basis).

$$Q_{sw(std)} = Q_s \left(\frac{528}{29.92} \right) \left(\frac{P_s}{T_s} \right) \quad \text{Equation 11}$$

Target Dilution Air Flow Rate, SCFM Wet.

$$Q_{dw(std)} = Q_{sw(std)} (DR - 1) \quad \text{Equation 12}$$

[**NOTE:** Assume a dilution ratio (DR) of between 10 and 50 in order to cool the stack gas to near ambient temperature.]

Target Sample Venturi Pressure Differential Setting.

$$\Delta H_1 = \left[\frac{29.92}{528} \frac{Q_s}{k_1} \frac{P_s}{T_s} \left(\frac{M_1 T_1}{P_1} \right)^{0.5} \right]^{1/n_1} \quad \text{Equation 13}$$

[**NOTE:** For Equation 13, M_1 is estimated to be equal to M_w which is calculated in Equation 2; T_1 is estimated to be 5 degrees higher than T_s ; and P_1 is estimated to be 0.4 to 0.5 inches Hg lower than P_s].

Target Dilution Venturi Pressure Differential Setting.

$$\Delta H_2 = \left[\frac{29.92}{528} \frac{Q_{dw(std)}}{k_2} \left(\frac{M_2 T_2}{P_2} \right)^{0.5} \right]^{1/n_2} \quad \text{Equation 14}$$

[**NOTE:** For this equation, M_{2est} is estimated to be 28.73 (assuming a moisture content (B_{ws}) of 1%; T_2 should be slightly higher (5 degrees) than ambient temperature (or higher if the dilution air is heated); and P_2 is estimated to be ± 0.5 inches Hg P_b].

Velocity of Stack Gas. Correct the mean preliminary velocity pressure for C_p and blockage using Equations 16, 17, and 18.

$$v_s = K_p C_p \left(\sqrt{(\Delta p)} \right)_{avg} \left[\sqrt{\frac{T_s}{P_s M_w}} \right] \quad \text{Equation 15}$$

Adjusted Velocity Pressure.

$$\Delta p_s = \Delta p_m \left[\frac{C_{p_r}}{C_p} \right]^2 \quad \text{Equation 16}$$

Average Probe Blockage Factor.

$$b_f = \frac{10.0}{A} \quad \text{Equation 17}$$

Adjusted Velocity Pressure. Substitute ΔP_{s2} for the ΔP 's measured during the preliminary traverse.

$$\Delta p_{s2} = \Delta p_{s1} \left[\frac{1}{(1 - b_f)} \right]^2 \quad \text{Equation 18}$$

Calculated Nozzle Diameter for Acceptable Sampling Rate.

$$D_n = \left[\frac{3.056 Q_s}{v_s} \right]^{0.5} \quad \text{Equation 19}$$

Nozzle Area

$$A_n = \pi \frac{D_n^2}{4} \frac{1}{144} \quad \text{Equation 20}$$

Velocity of Gas in Nozzle

$$v_n = \frac{\left(\frac{Q_s}{60} \right)}{A_n} \quad \text{Equation 21}$$

Minimum Nozzle/Stack Velocity Ratio Parameter. Equations 22 and 23 are identical to equations presented in Method 201A of Appendix M to 40 CFR part 51.

$$R_{\min} = \left[0.2457 + \left(0.3072 - \frac{0.2603(\mu)(Q_s)^{0.5}}{v_n^{1.5}} \right)^{0.5} \right] \quad \text{Equation 22}$$

Maximum Nozzle/Stack Velocity Ratio Parameter.

$$R_{\max} = \left[0.4457 + \left(0.5690 + \frac{0.2603(\mu)(Q_s)^{0.5}}{v_n^{1.5}} \right)^{0.5} \right] \quad \text{Equation 23}$$

Minimum Gas Velocity for $R_{\min} \leq 0.5$.

$$v_{\min} = v_n (0.5) \quad \text{Equation 24}$$

Minimum Gas Velocity for $R_{\min} > 0.5$. Equations 24 and 25 are identical to equations presented in Method 201A of Appendix M to 40 CFR part 51.

$$v_{\min} = v_n R_{\min} \quad \text{Equation 25}$$

Maximum Gas Velocity for $R_{\max} \leq 1.5$.

$$v_{\max} = v_n R_{\max} \quad \text{Equation 26}$$

Maximum Gas Velocity for $R_{\max} > 1.5$.

$$v_{\max} = v_n (1.5) \quad \text{Equation 27}$$

Minimum Velocity Pressure.

$$\Delta p_{\min} = 1.3686 \times 10^{-4} \left[\frac{P_s M_w}{T_s} \right] \left[\frac{v_{\min}}{C_p} \right]^2 \quad \text{Equation 28}$$

Maximum Velocity Pressure.

$$\Delta p_{\max} = 1.3686 \times 10^{-4} \left[\frac{P_s M_w}{T_s} \right] \left[\frac{v_{\max}}{C_p} \right]^2 \quad \text{Equation 29}$$

Sampling Time at Point 1. Equation 30 is identical to an equation presented in Method 201A of Appendix M to 40 CFR part 51. You must use the preliminary velocity traverse data.

$$t_1 = \left(\frac{Dp'_1}{Dp'_{\text{avg}}} \right)^{0.5} \left(\frac{t_r}{N} \right) \quad \text{Equation 30}$$

12.4.2 Calculations During the Test.

Sampling Time at Point n. You must use the actual test run data at each point, n, and test run point 1.

$$t_n = t_1 \frac{\sqrt{\Delta p_n}}{\sqrt{\Delta p_1}} \quad \text{Equation 31}$$

12.4.3 Calculations After the Conclusion of the Test. The following calculations must be performed after the test in order to determine if the appropriate PM₁₀ and PM_{2.5} cut sizes were sampled and the method criteria met.

Mixed Gas At RH Sensor Pressure (absolute).

$$P_3 = P_b - \frac{\text{Pump } g}{13.6} \quad \text{Equation 32}$$

Sample Venturi Gas Pressure (absolute).

$$P_1 = P_3 + \frac{P_3 + \frac{\Delta H_1}{2.5}}{13.6} \quad \text{Equation 33}$$

NOTE: For equations 33 and 34, Δp_{mix} is the pressure differential measured across the mixed air blower (after the filter holder) and dilution air blower.

Dilution Venturi Air Pressure (absolute).

$$P_2 = P_3 + \frac{\Delta p_{\text{mix}} + \frac{\Delta H_{\text{dil}}}{2.5}}{13.6} \quad \text{Equation 34}$$

Water Vapor Pressure of Dilution Air (absolute).

$$P_{v_2} = \frac{\text{RH}_{\text{dil}}}{100} \times 10^{\left(6.6911 - \frac{3144}{T_{\text{mix}} - 69.14}\right)} \quad \text{Equation 35}$$

Water Vapor Pressure of Mixed Air.

$$P_{V_3} = \frac{RH_{\text{mixed}}}{100} \times 10^{\left(6.6911 - \frac{3144}{T_{\text{mix}} - 69.14}\right)}$$
Equation 36

Molecular Weight of Dilution Air, Wet.

$$M_2 = 28.84 \left(1 - \frac{P_{V_2}}{P_2}\right) + 18 \left(\frac{P_{V_2}}{P_2}\right)$$
Equation 37

Molecular Weight of Mixed Gas, Wet.

$$M_3 = 28.84 \left(1 - \frac{P_{V_3}}{P_3}\right) + 18 \left(\frac{P_{V_3}}{P_3}\right)$$
Equation 38

Sample Flow Rate At Sample Venturi Conditions.

$$Q_1 = K_1 \Delta H_{sv}^{(n_1)} \left(\sqrt{\left(\frac{T_{sv}}{M_1 P_1} \right)} \right)$$
Equation 39

Sample Flow Rate At Cyclone (Stack) Conditions. Q_s is recalculated using actual stack temperatures and pressures measured during the run.

$$Q_s = Q_1 \left(\frac{T_s}{T_{sv}} \right) \left(\frac{P_1}{P_s} \right)$$
Equation 40

Dilution Air Flow Rate At Dilution Venturi Conditions).

$$Q_2 = K_2 \Delta H_{dv}^{(n_2)} \left(\sqrt{\left(\frac{T_{dil}}{M_2 P_2} \right)} \right)$$
Equation 41

Mixed Gas Total Flow Rate (at ambient conditions).

$$Q_{33} = Q_1 \left(\frac{P_1}{P_3} \right) \left(\frac{T_3}{T_1} \right) \left(\frac{M_1}{M_3} \right) + Q_2 \left(\frac{P_2}{P_3} \right) \left(\frac{T_3}{T_2} \right) \left(\frac{M_2}{M_3} \right)$$
Equation 42

Mixed Gas Water Vapor Flow Rate.

$$Q_{w33} = Q_{33} \left(\frac{P_{v3}}{P_3} \right) \quad \text{Equation 43}$$

Dilution Air Water Vapor Flow Rate.

$$Q_{w22} = Q_2 \left(\frac{P_{v2}}{P_2} \right) \quad \text{Equation 44}$$

Water Vapor Flow Rate From Sample @ Mixed Conditions.

$$Q_{ws3} = Q_{w33} - Q_{w22} \left(\frac{T_{\text{mix}}}{P_3} \right) \left(\frac{P_2}{P_3} \right) \left(\frac{M_2}{M_3} \right) \quad \text{Equation 45}$$

Dilution Air Flow Rate (at dry standard conditions).

$$Q_{d(\text{std})} = P_2 \left(\frac{Q_2}{T_{\text{dil}}} \right) \left(\frac{1 - P_{v2}}{P_2} \right) \left(\frac{528}{29.92} \right) \quad \text{Equation 46}$$

Sample Flow Rate At Standard Conditions, SCFM Dry.

$$Q_{s(\text{std})} = \frac{528}{29.92} Q_1 \left[\frac{(1 - B_{ws})}{1} \right] \left[\frac{P_1}{T_{sv}} \right] \quad \text{Equation 47}$$

Moisture Content of Stack Gas.

$$B_{ws} = \frac{Q_{w(s3)}}{Q_1} \times \frac{P_3}{P_1} \times \frac{M_3}{M_1} \times \frac{T_s}{T_3} \quad \text{Equation 48}$$

Dilution Ratio.

$$DR = \frac{Q_{s(\text{std})} + Q_{d(\text{std})}}{Q_{s(\text{std})}} \quad \text{Equation 49}$$

Actual Particle Cut Diameter for Cyclone I. This is based on actual temperatures and pressures measured during the test run.

$$D_{50} = 0.15625 \left[\frac{T_s}{M_w P_s} \right]^{0.2091} \left[\frac{\mu}{Q_s} \right]^{0.7091} \quad \text{Equation 50}$$

Particle Cut Diameter for $N_{re} < 3162$ for Cyclone IV. C must be recalculated using the actual test run data and a D_{50} (D_p) of 2.5.

$$D_{50} = 0.0024302 \left[\frac{\mu}{Q_s} \right]^{1.1791} \left[\frac{1}{C} \right]^{0.5} \left[\frac{T_s}{P_s M_w} \right]^{0.6790} \quad (N_{re} < 3162) \quad \text{Equation 51}$$

NOTE: The viscosity and Reynolds Number must be recalculated using the actual stack temperature, moisture, and oxygen content.

Particle Cut Diameter for $N_{re} \geq 3162$ for Cyclone IV. C must be recalculated using the actual test run data and a D_{50} (D_p) of 2.5.

$$D_{50} = 0.019723 \left[\frac{\mu}{Q_s} \right]^{0.8058} \left[\frac{1}{C} \right]^{0.5} \left[\frac{T_s}{P_s M_w} \right]^{0.3058} \quad (N_{re} \geq 3162) \quad \text{Equation 52}$$

Re-estimated Cunningham Correction Factor. You must use the actual test run Reynolds Number (N_{re}) value and select the appropriate D_{50} from Equation 50 or 51 (or Equation 54 or 55 if reiterating).

$$C_r = 1 + 0.0057193 \left[\frac{\mu}{P_s D_{50}} \right] \left[\frac{T_s}{M_w} \right]^{0.5} \quad \text{Equation 53}$$

Re-calculated Particle Cut Diameter for $N_{re} < 3162$.

$$D_{50-1} = 0.0024302 \left[\frac{\mu}{Q_s} \right]^{1.1791} \left[\frac{1}{C_r} \right]^{0.5} \left[\frac{T_s}{P_s M_w} \right]^{0.6790} \quad (N_{re} < 3162) \quad \text{Equation 54}$$

Re-calculated Particle Cut Diameter for $N_{re} \geq 3162$.

$$D_{50-1} = 0.019723 \left[\frac{\mu}{Q_s} \right]^{0.8058} \left[\frac{1}{C_r} \right]^{0.5} \left[\frac{T_s}{P_s M_w} \right]^{0.3058} \quad (N_{re} \geq 3162) \quad \text{Equation 55}$$

Ratio (Z) Between D_{50} and D_{50-1} Values.

$$Z = \frac{D_{50-1}}{D_{50}} \quad \text{Equation 56}$$

Acceptance Criteria for Z Values. The number of iterative steps is represented by N.

$$0.99 \leq \left[Z = \left(\frac{D_{50N}}{D_{50N+1}} \right) \right] \leq 1.01 \quad \text{Equation 57}$$

Volume Sampled At Standard Conditions, Dry SCF.

$$V_{s(\text{std})} = Q_{s(\text{std})} \theta \quad \text{Equation 58}$$

Percent Isokinetic Sampling.

$$I = \left(\frac{100 T_s V_{s(\text{std})}^{29.92}}{60 v_s \theta A_n P_s (1 - B_{ws}) 528} \right) \quad \text{Equation 59}$$

Acetone Blank Concentration.

$$C_a = \frac{m_a}{V_a \rho_a} \quad \text{Equation 60}$$

Acetone Blank Weight To Be Subtracted.

$$W_a = C_a V_{aw} \rho_a \quad \text{Equation 61}$$

Concentration of $PM_{2.5}$ Collectable Particulate Matter, gr/DSCF.

$$C_{PM2.5} = \left(\frac{7000}{453,592} \right) \left(\frac{m_3 + m_f}{V_{s(\text{std})}} \right) \quad \text{Equation 62}$$

Concentration of Coarse $PM_{<10>2.5}$ Collectable Particulate Matter, gr/DSCF.

$$C_{PM10-2.5} = \left(\frac{7000}{453,592} \right) \left(\frac{m_2}{V_{s(\text{std})}} \right) \quad \text{Equation 63}$$

Concentration of PM₁₀ Collectable Particulate Matter, gr/DSCF.

$$C_{PM10} = \left(\frac{7000}{453,592} \right) \left(\frac{m_2 + m_3 + m_f}{V_{s(std)}} \right) \quad \text{Equation 64}$$

Concentration of PM_{>10} Collectable Particulate Matter, gr/DSCF.

$$C_{PM > 10} = \left(\frac{7000}{453,592} \right) \left(\frac{m_1}{V_{s(std)}} \right) \quad \text{Equation 65}$$

Concentration of Total Collectable Particulate Matter, gr/DSCF.

$$C_{Total} = \left(\frac{7000}{453,592} \right) \left(\frac{m_1 + m_2 + m_3 + m_f}{V_{s(std)}} \right) \quad \text{Equation 66}$$

13. METHOD PERFORMANCE

[Reserved]

14. POLLUTION PREVENTION

[Reserved]

15. WASTE MANAGEMENT

[Reserved]

16. REFERENCES

We used the following references in the development of this test method:

Dawes, S.S., and W.E. Farthing. "Application Guide for Measurement of PM_{2.5} at Stationary Sources," U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC, 27511, EPA-600/3-90/057 (NTIS No.: PB 90-247198), November 1990.

U.S. Environmental Protection Agency, Federal Reference Methods 1 through 5 and Method 17, 40 CFR 60, Appendix A.

U.S. Environmental Protection Agency, Federal Reference Method 201A, 40 CFR 51, Appendix M.

Richards, J.R. "Test protocol: PCA PM₁₀/PM_{2.5} Emission Factor Chemical Characterization Testing," PCA R&D Serial No. 2081, Portland Cement Association, 1996.

Mobley, D.J., "Additional Guidance on PM_{2.5} Cassette Handling and Transportation," U.S. Environmental Protection Agency; Emissions, Monitoring & Analysis Division; January 19, 2000.

17. TABLES, DIAGRAMS, FLOWCHARTS, AND VALIDATION DATA

You must use the following tables, diagrams, flowcharts, and data to complete this test method successfully.

Table 1. Typical Particulate Matter Concentrations

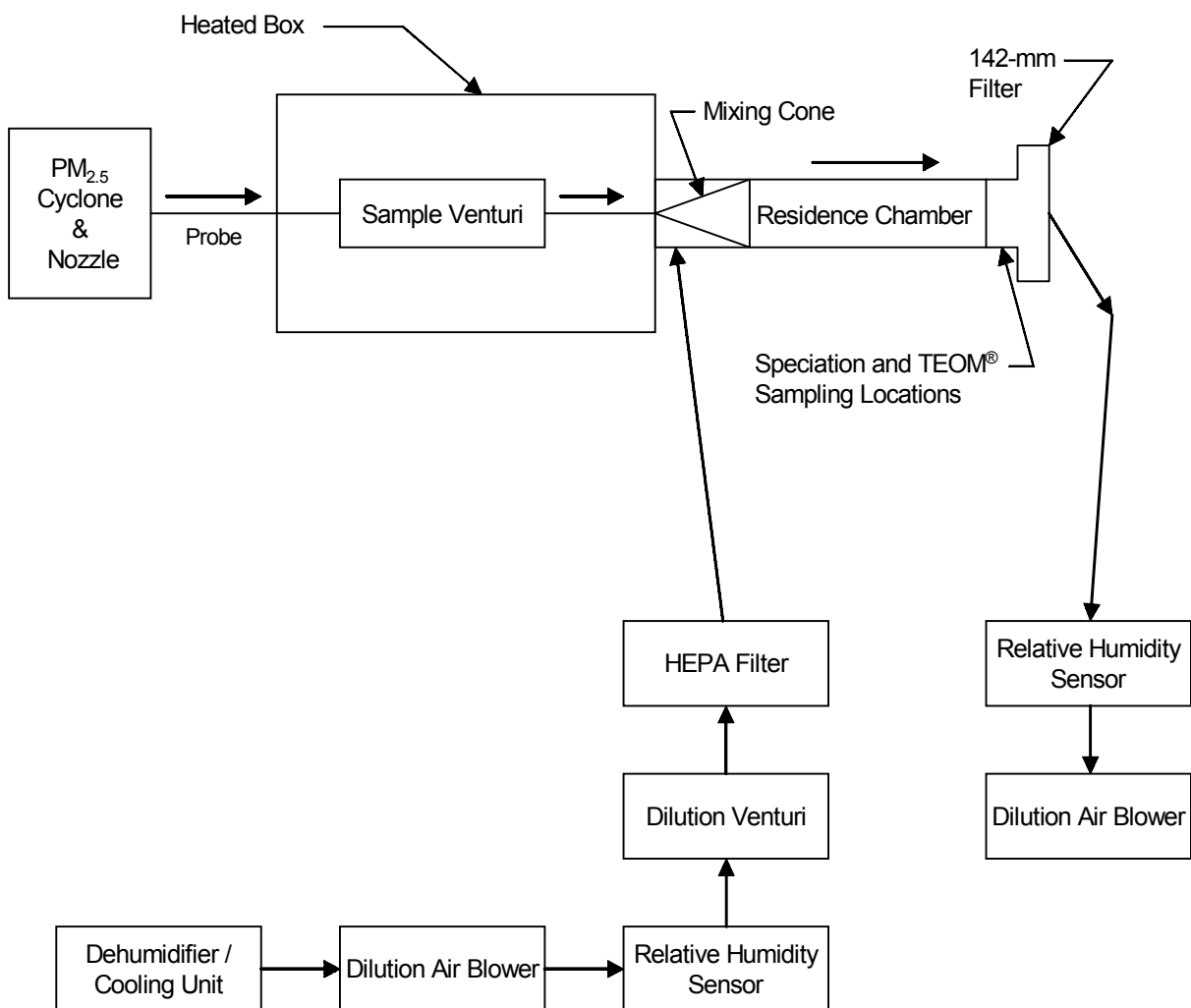
Particle Size Range	Concentration and % by Weight
Total collectable particulate	0.015 gr/DSCF
≤ 10 and > 2.5 micrometers	40% of total collectable particulate matter
≤ 2.5 micrometers	20% of total collectable particulate matter

Table 2. Required Cyclone Cut Diameters (D_{50})

Cyclone	Min. Cut Diameter, Micrometer	Max. Cut Diameter, Micrometer
PM ₁₀ Cyclone (Cyclone I from five stage cyclone)	9	11
PM _{2.5} Cyclone (Cyclone IV from five stage cyclone)	2.25	2.75

Table 3. ΔH_1 Values Based on Preliminary Traverse Data

Stack Temperature, ($^{\circ}$ R)	$T_s - 50^{\circ}$	T_s	$T_s + 50^{\circ}$
ΔH_1 , (in. W.C.)	-	-	-

**Figure 1. FPM-DST Schematic**

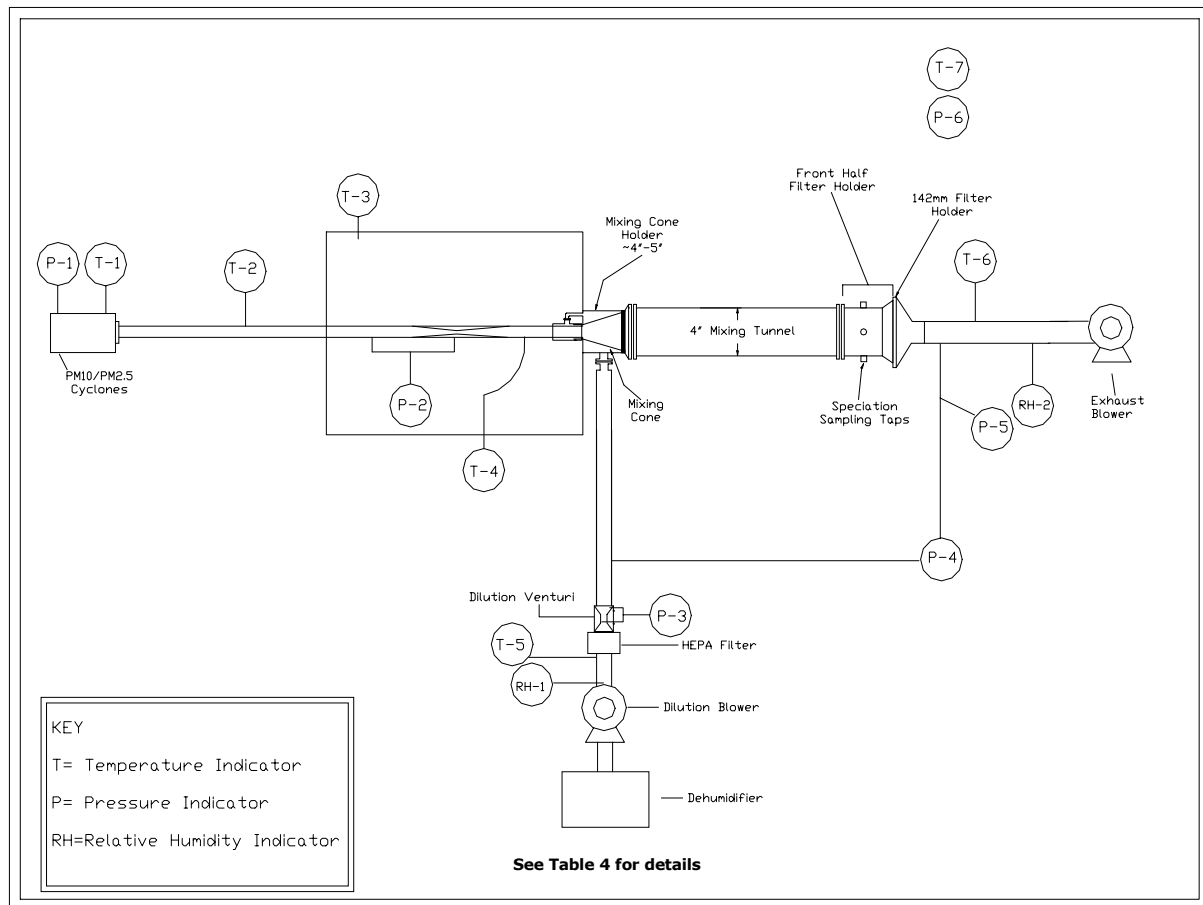
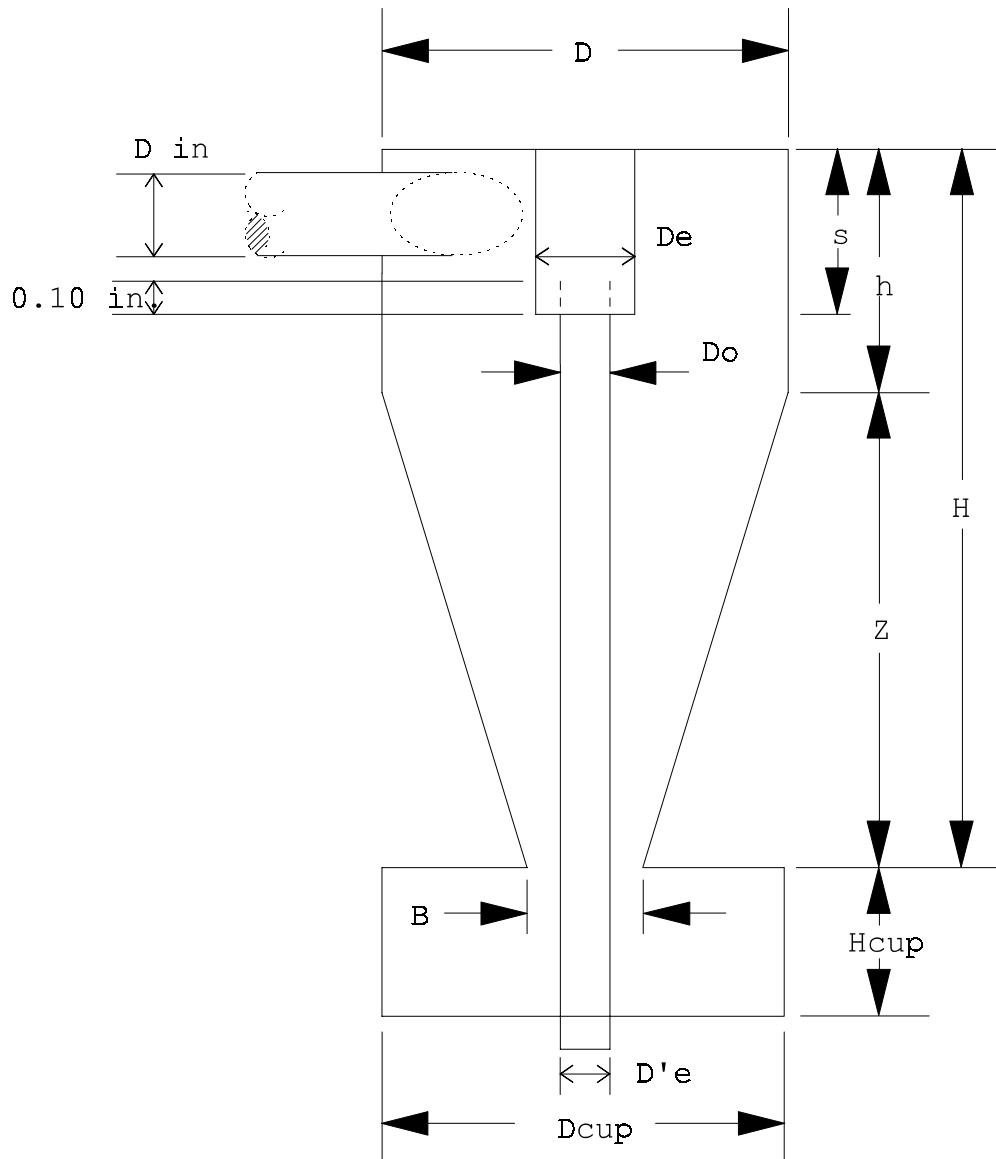


Figure 2. FPM-DST Pressure and Sensor Lines Layout.

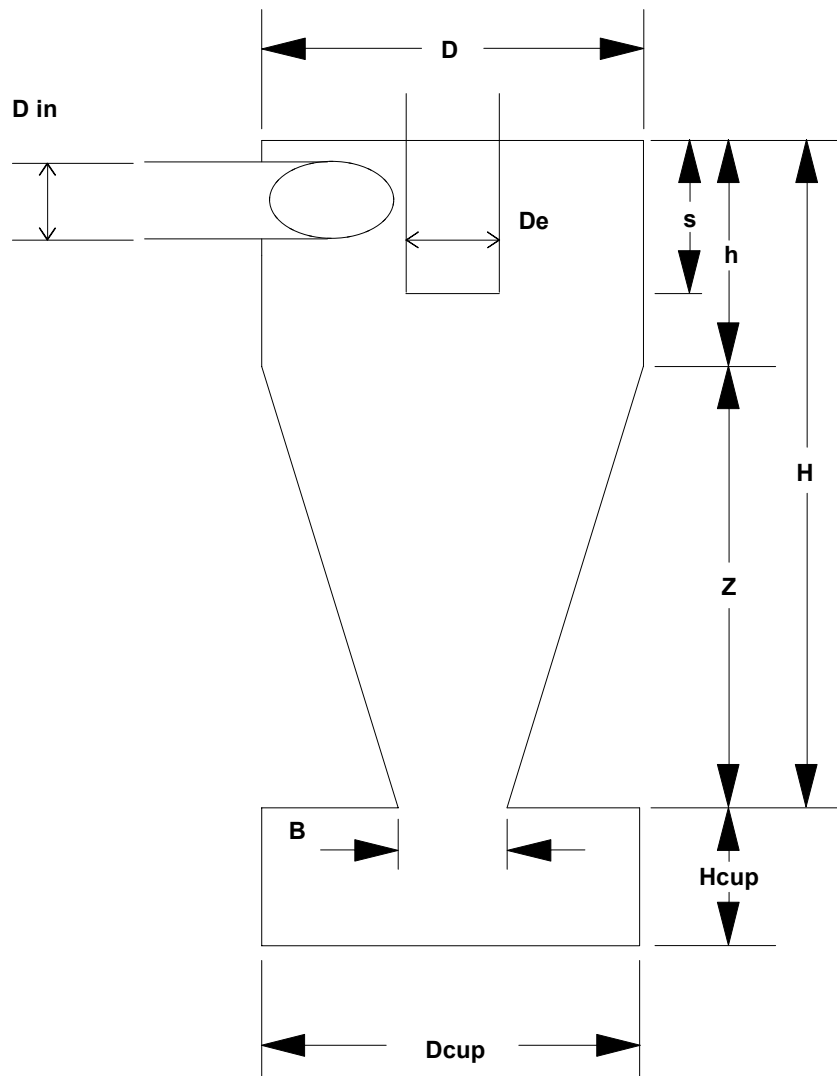
Table 4. Dilution Sampler Instrument List

Instrument Code (Figure 2)	Description	Suggested Range	Corresponding Equation Variables
T-1	Stack Gas Temperature	0-300°C	T_s
T-2	Stack Probe Temperature	0-300°C	---
T-3	Sample Venturi Enclosure Temperature	0-300°C	---
T-4	Sample Venturi Temp	0-300°C	T_{sv}
T-5	Dilution Air Temp	0-50°C	T_{dil}
T-6	Mixed Air Temperature	0-50°C	T_{mix}
T-7	Ambient Temperature	0-50°C	---
P-1	Stack Pressure	0-50 inches water Δp_m	P_g
P-2	Sample Venturi	0-5 inches water Δp	ΔH_1
P-3	Dilution Venturi Pressure Differential	0-5 inches water Δp	ΔH_2
P-4	Dilution Air/Mixed Air Pressure Differential	0-30 inches water Δp	Δp_{mix}
P-5	Pump Pressure	0-30 inches water Δp	P_{ump_g}
P-6	Atmospheric Pressure		P_{bar}
RH-1	Relative Humidity of Dilution Air	0-100 Percent	RH_1
RH-2	Relative Humidity of Mixed Air	0-100 Percent	RH_2



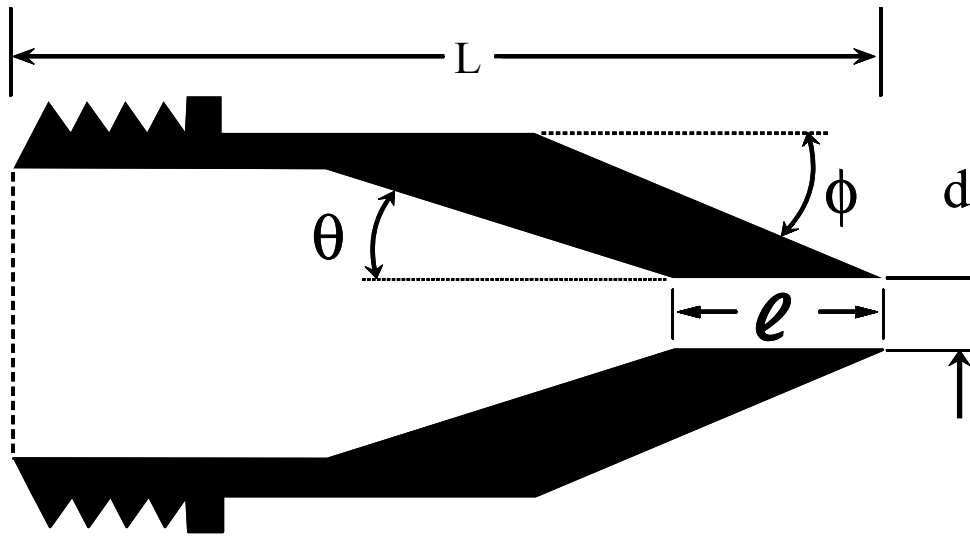
Cyclone I (10 Micrometer)	Cyclone Interior Dimensions (cm \pm 0.02 cm)											
	Din	D	De	B	H	h	Z	S	Hcup	Dcup	De'	Do
	1.27	4.47	1.50	1.88	6.95	2.24	4.71	1.57	2.25	4.45	1.02	1.24

Figure 3. Design specifications for Cyclone I (10 Micrometer)



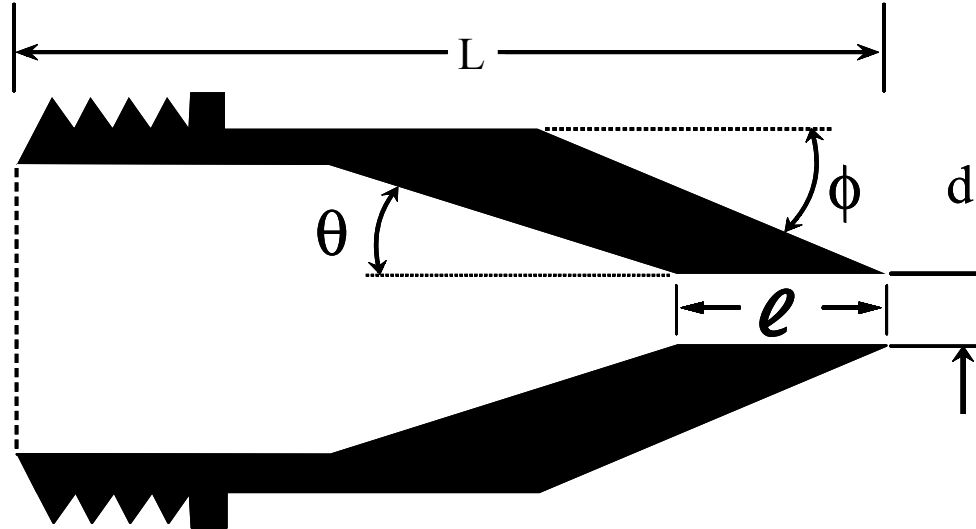
Cyclone IV (2.5 Micrometer)	Cyclone Interior Dimensions (cm \pm 0.02 cm)									
	D_{in}	D	D_e	B	H	h	Z	S	H_{cup}	D_{cup}
	0.51	2.54	0.59	1.09	2.68	1.03	1.65	0.58	2.22	2.62

Figure 4. Design Specifications for Cyclone IV (2.5 Micrometer) Sizing Device



Nozzle diameter, d (inches)	Cone Angle, θ (degrees)	Outside taper, ϕ (degrees)	Straight inlet length, e (inches)	Total Length, L (inches)
For PM ₁₀ Sizer				
0.125	4	15	<0.05	2.710±0.05
0.136	4	15	<0.05	2.653±0.05
0.150	4	15	<0.05	2.553±0.05
0.164	5	15	<0.05	1.970±0.05
0.180	6	15	<0.05	1.572±0.05
0.197	6	15	<0.05	1.491±0.05
0.215	6	15	<0.05	1.450±0.05
0.233	6	15	<0.05	1.450±0.05
0.264	5	15	<0.05	1.450±0.05
0.300	4	15	<0.05	1.480±0.05
0.342	4	15	<0.05	1.450±0.05
0.390	3	15	<0.05	1.450±0.05

Figure 5. PM₁₀ Sizer Nozzle Design Specifications



Nozzle diameter, d (inches)	Cone Angle, θ (degrees)	Outside taper, ϕ (degrees)	Straight inlet length, l (inches)	Total Length, L (inches)
For PM _{2.5} Sizer				
0.125	3	15	<0.05	1.450±0.05
0.138	2	15	<0.05	1.450±0.05
0.156	1	15	<0.05	1.450±0.05
0.172	1	15	<0.05	1.450±0.05
0.188	1	15	<0.05	1.450±0.05
0.200	0	15	<0.05	1.450±0.05

Figure 6. PM_{2.5} Sizer Nozzle Design Specifications

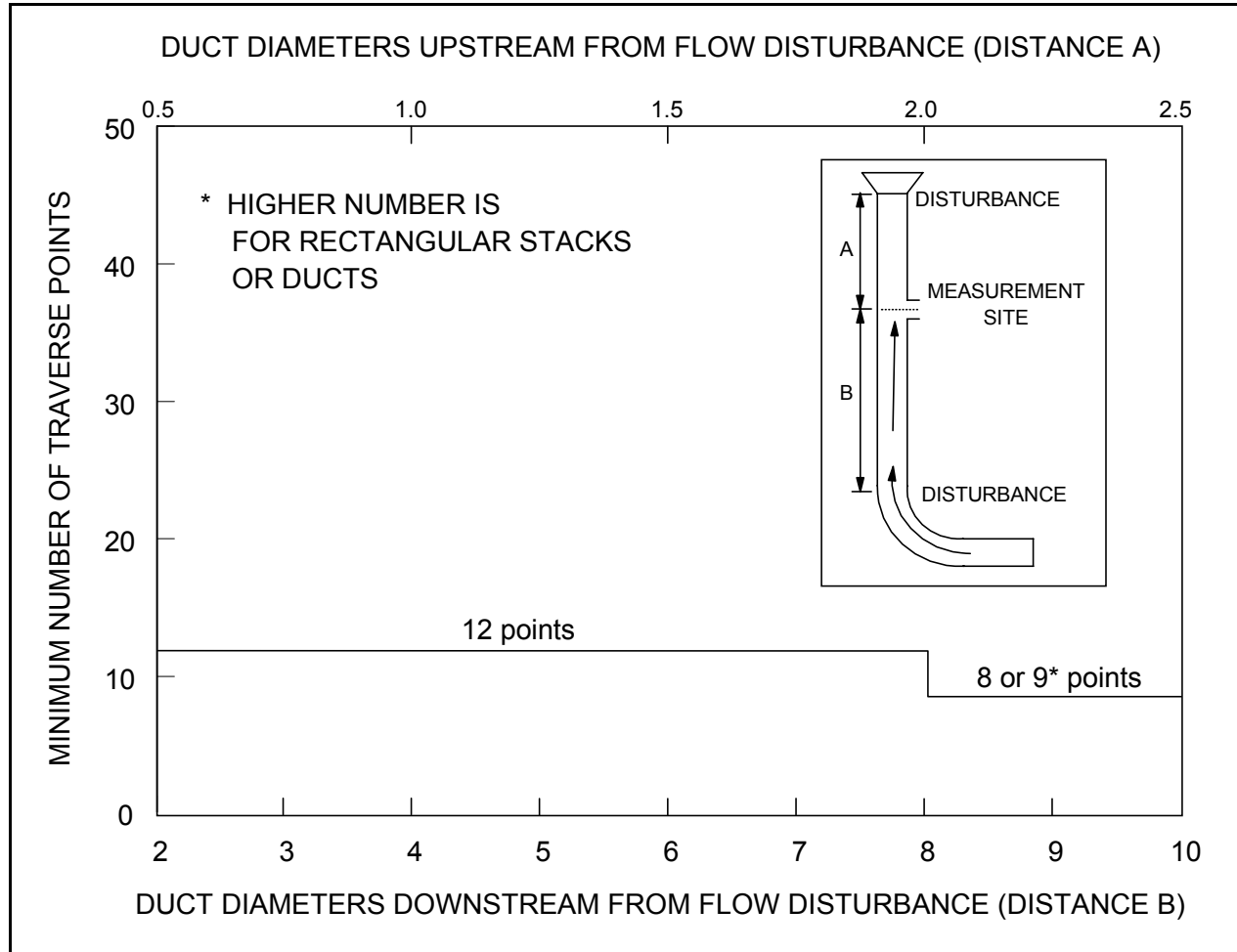


Figure 7. Minimum Number of Traverse Points for Draft Method Traverse

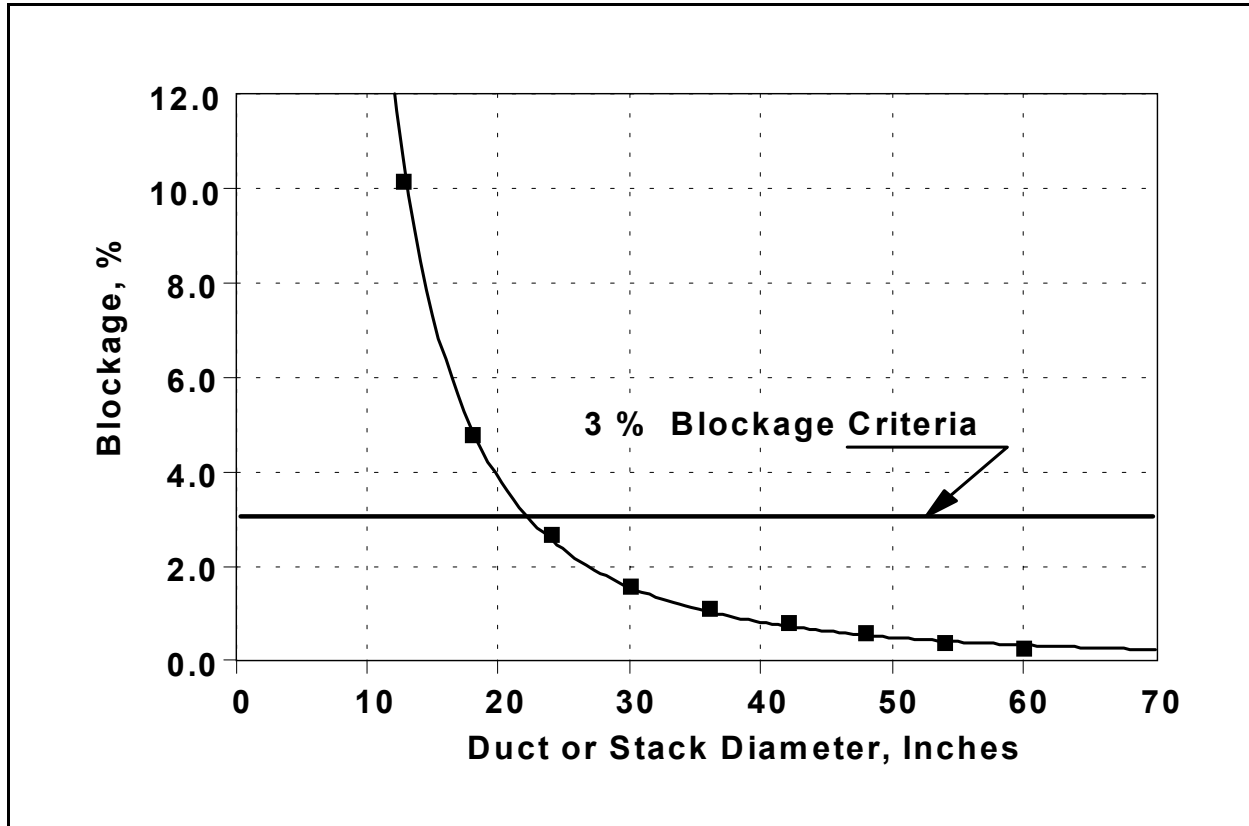


Figure 8. Gas Flow Blockage by the Combined Cyclone Sampling Head

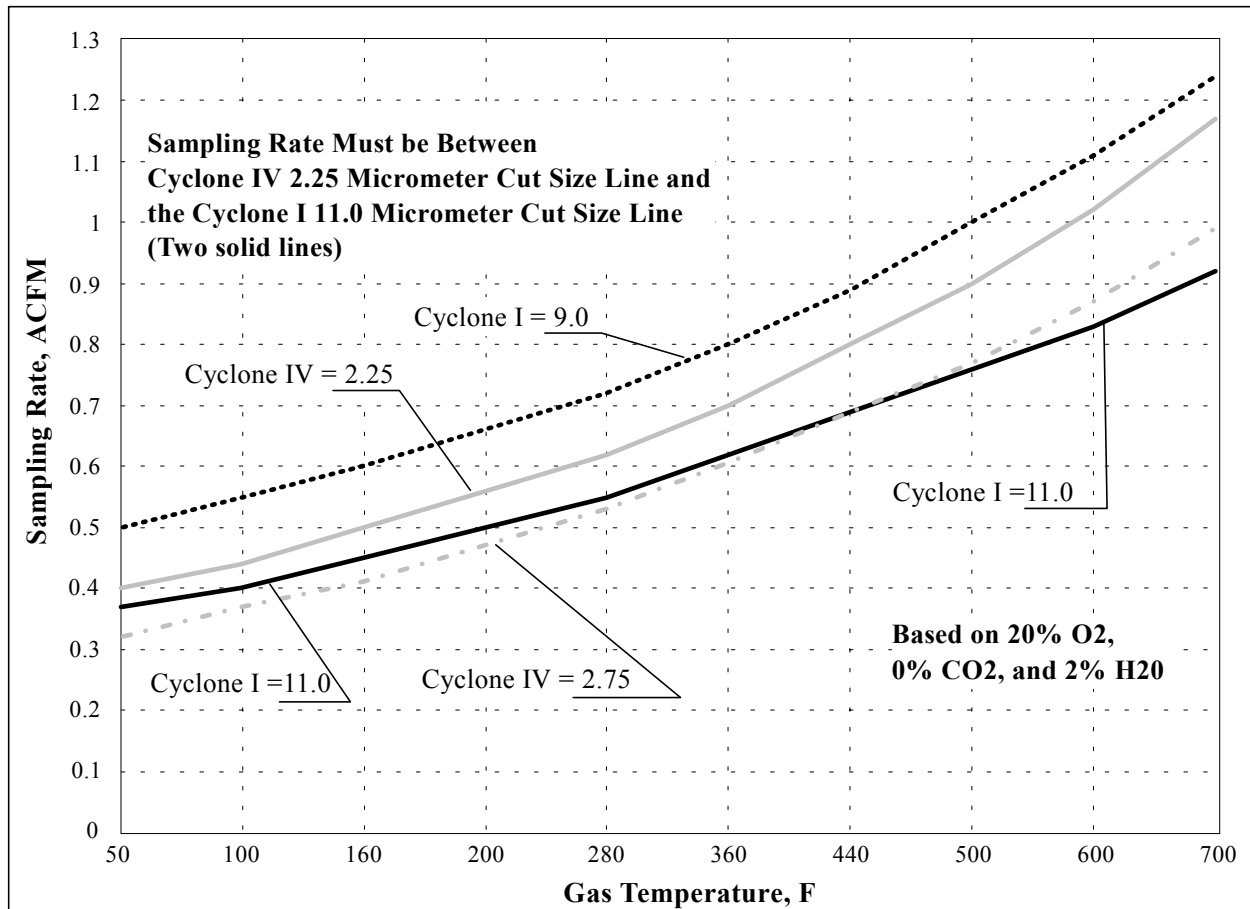


Figure 9. Acceptable Sampling Rate for Combined Cyclone Heads